General and Engineering Geology of the Wray Area, Colorado and Nebraska

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GENERAL AND ENGINEERING GEOLOGY OF THE WRAY AREA COLORADO-NEBRASKA

By Dorothy R. Hill and Jessie M. Tompkin

ABSTRACT

The Wray area, consisting of the Wray no. 3 and Wray no. 4 15-minute quadrangles, includes part of eastern Yuma County in eastern Colorado, and part of southwestern Dundy County in southwestern Nebraska. The North Fork of the Republican River flows eastward through the area, joining the Arikaree River just east of the Wray no. 4 quadrangle. North of the Republican River are northwestward-trending sand hills, alternating with flat, silty, sandy farmlands. The Ogallala formation forms steep cliffs along the southern side of the valley of the Republican River, and the rolling uplands south of the cliffs are covered with loess.

The Wray quadrangles lie on the eastern flank of the Julesburg Basin, which forms a great structural trough extending along the foothills of the Rocky Mountain Front Range from southern Wyoming to southern Colorado, and eastward into eastern Wyoming, western Nebraska, and northwestern Kansas. The formations exposed in the Wray quadrangles are flat-lying, or have only a slight dip not discernible in outcrops. The oldest formation is the Pierre shale, of Late Cretaceous age, which is unconformably overlain by the Ogallala formation, of Pliocene age. The Ogallala formation consists of sands, silts, and gravels which are cemented to varying degrees by calcium carbonate. The beds are discontinuous; none can be traced more than a few hundred feet. Unconformably overlying the Ogallala formation are the Pleistocene Grand Island formation and the Pleistocene and Recent sandy silt and clay. South of the Republican River, the Grand Island formation and the sandy silt and clay are absent, and the Pleistocene Peorian loess rests directly on the Ogallala formation. North of the Republican River, where very little loess is present, the Grand Island formation and the sandy silt and clay are overlain in some places by sand hills. Valley fill chokes the ravines of streams tributary to the Republican River.

The Pierre shale was deposited in the vast inland Cretaceous sea which covered eastern Colorado and much of the surrounding area. After formation of the Julesburg Basin at the end of Cretaceous time, the Pierre shale was eroded and the Pliocene Ogallala formation was deposited by fresh-water streams flowing over the irregular surface of the Pierre shale. During Pleistocene time, streams cut deep valleys in the Ogallala formation and deposited the sand and gravel of the Grand Island formation in the valleys. After much of the sand and gravel was removed by erosion, the valleys were choked with valley fill or with wind-blown Peorian loess. South of the Republican River, a thick mantle of undisturbed loess covered the surface, and north of the Republican River the loess mantle was reworked by streams and covered by sand drifting into the area from the north. In late Pleistocene and Recent time, streams cut terraces in the valley fill.

Most of the formations in the Wray area are fair foundation materials, although good construction materials are scarce. The gravel of the Grand Island formation

and the gravels in the Ogallala formation contain large quantities of clay, silt, sand, and calcium carbonate, and have very few pebbles larger than one-half inch in diameter. None of the gravel is suitable for concrete aggregate, but it may be used for ballast, base- and top-course. Volcanic ash in the Ogallala formation may be used as mineral filler, pozzolanic material, and cleansing powders. The Pleistocene sandy silt and clay may be used for binder; the Peorian loess is a possible source of ceramic slag aggregate and serves as a good mineral filler. Blending sand and earth-fill dam material are available in the valley fill.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Wray area, consisting of the Wray no. 3 and Wray no. 4 15-minute quadrangles, includes part of eastern Yuma County in eastern Colorado and part of southwestern Dundy County in southwestern Nebraska. The quadrangles cover an area of approximately 440 square miles, which extends northward from the 40th parallel to latitude 40°15′ N., and westward from longitude 102° to 102°30′ W. The location of the area is shown in figure 1.

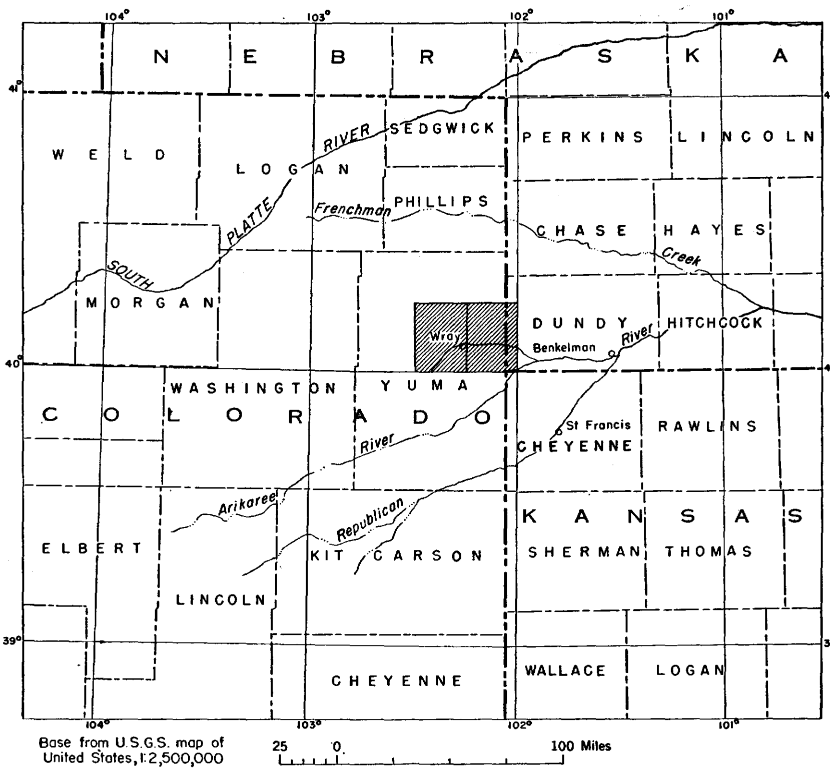

FIGURE 1.—Index map showing location of the Wray area.

The Wray area can be reached by east-west U. S. Highway 34, which is surfaced with oiled gravel. The Chicago, Burlington & Quincy Railroad follows a route approximately parallel to this highway. State Highway 51, which is a graded gravel road, extends north and south from the town of Wray. State Highway 27 extends north and south from the town of Eckley, and State Highway 29 branches south from U. S. Highway 34, 2 miles west of Wray. Both Highways 27 and 29 are graded and graveled. Light-traffic section-line roads are maintained by grading.

PURPOSE OF INVESTIGATION

The Wray area is part of the Missouri River basin, which is now being developed. The comprehensive plan for the development of the Missouri River basin includes the construction by the Bureau of Reclamation of the Wray dam and reservoir on the North Fork of the Republican River in the Wray no. 3 quadrangle (S. Doc. 191, 1944). The approximate proposed location of the dam is shown on figure 2. Because part of the program of the Engineering Geology Branch of the U. S. Geological Survey is to supply background geologic maps of areas where construction is proposed by other Federal agencies, the mapping of the area surrounding the proposed Wray dam and reservoir was undertaken by the Survey in the summer of 1948.

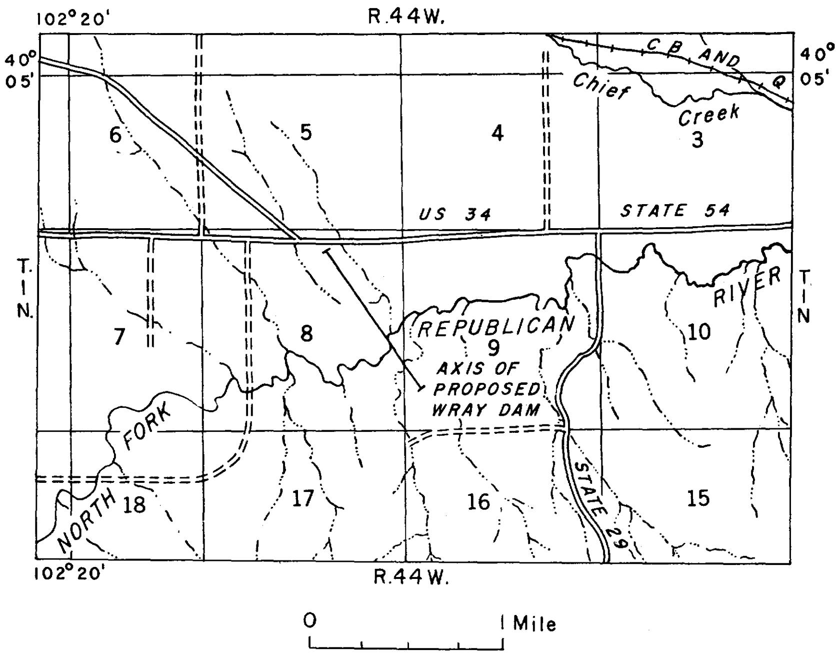

FIGURE 2.—Map showing approximate proposed location of Wray Dam.

The aim of this report is twofold. It is intended to be of value not only to persons interested in the geology of the Wray quadrangles, but also to anyone who must know the engineering properties of the geologic units or who desires to use construction materials.

The report is divided into two parts. The first, a discussion of the map units shown on the accompanying geologic map, includes descriptive geology and geologic history. The descriptive geology covers the extent, distribution, lithology, paleontology, age, and soil development of each map unit. The next, a summary of the engineering geology of the area, discusses the engineering problems and construction materials for each map unit. All geologic materials in the area that might be used for construction are considered. Logs for wells shown on the geologic map are given in an appendix at the end of the report.

FIELD WORK

The field work on which this report is based was accomplished by the writers during the summer of 1948 under the general supervision of E. B. Eckel and E. Dobrovolny of the Engineering Geology Branch, U. S. Geological Survey. The geology was mapped directly on aerial photographs provided by the Soil Conservation Service of the Department of Agriculture, and culture and drainage were transferred from the photographs to the finished map (see pl. 1) by means of a vertical sketchmaster. Boundaries of the quadrangles were furnished by the Topographic Division of the U. S. Geological Survey; the section-line grid was established from Bureau of Land Management survey plats. The elevations on which the cross section was based were determined by vertical-angle measurement from bench marks established by the U. S. Coast and Geodetic Survey. Other elevations were obtained by using an altimeter; these measurements were accurate only within 10 feet. Units 3 feet or more in thickness were shown on the geologic map. Samples of sand, gravel, silt, volcanic ash, and other possible construction materials were tested by the writers in the laboratory at the end of the field season to determine the uses for which they were best fitted.

ACKNOWLEDGMENTS

The writers are indebted to Mr. R. E. Fincher of the Public Roads Laboratory, Denver, who generously supervised the analysis of the samples of construction material. The Wray office of the Production and Marketing Administration furnished aerial photographs which were used at the beginning of the field season. Also, many residents of the Wray area offered generous cooperation and assistance during the course of the field work.

GEOGRAPHY

PHYSIOGRAPHY

The most striking feature of the present physiography of the Wray area is the northwest trend of the surface deposits. Two-thirds of the area north of the Republican River is covered by sand hills interspersed with poorly drained sandy flats. South of the Republican River, steep bluffs are cut by numerous northwest-sloping ravines. The surface undulations of the loess deposits surmounting the bluffs also trend northwest. Maximum local relief is 170 feet, which is the height of the highest sand hill. The almost vertical cliffs south of Wray are the most arresting feature of the relief. These cliffs rise as high as 150 feet above the flat valley bottom of the Republican River and contrast sharply with the rolling topography of the surrounding countryside.

The Wray quadrangles are in the High Plains Section of the Great Plains province, on the broad, irregular plain that slopes from the Rocky Mountains eastward to the Mississippi Valley. The North Fork of the Republican River flows eastward through the southern part of the area and is bordered on the south by bluffs which are highest near the town of Wray, become lower toward the east, and finally disappear near the Colorado-Nebraska line. South of the bluffs are rolling uplands, which are cut by northwestward-heading ravines joining the valley of the Arikaree River; both bluffs and uplands are cut by numerous small southward- and southeastward-heading streams tributary to the Republican River. North of the Republican River, many long northwestward-trending ridges of sand hills, 25 to 170 feet high, alternate with wide, poorly drained flats. The northwesterly trend is repeated in the pattern of ridges and hollows in the loess deposits on the uplands south of the Republican River. The trend of the loess ridges is quite marked on aerial photographs, although it is not easily discerned on the ground. Total relief of the area is about 500 feet and the average altitude is 3,750 feet.

DRAINAGE AND WATER SUPPLY

The two largest streams in the Wray area are the North Fork Republican River, and the Arikaree River, both of which flow northeastward; many small intermittent streams flow into these rivers from the northwest and the south. Wells produce water from gravel 50 to 150 feet below the surface. The main aquifers in the area are the gravel of both the Grand Island formation and the Ogallala formation. At the present time, well water is used mostly for domestic purposes and stock. Very little irrigation is practiced.

The North Fork Republican River heads south of the southern border of Wray no. 3 quadrangle, about 5 miles east of its western boundary. It flows 4 miles northeast, then bends to flow eastward through the town of Wray and the Wray no. 4 quadrangle. About 1 mile west of Wray, it is joined by Chief Creek which heads in a marshy area about 2 miles east of the town of Eckley. The North Fork Republican River is fed by many small springs and has an average flow of about 22 cubic feet per second. The flow is very uniform and is seldom less than 10 cubic feet per second (Colby and Altman, 1948, p. 98). Many south-heading intermittent streams discharge into the river during the spring, but only a few small streams flow into the river from the northwest. The ravines formed by the streams extend as much as 2 miles from the river valley. Most of the upland area has no surface drainage. Although the drainage area of the North Fork Republican River upstream from the gaging station near Wray contains 650 square miles, only about 40 square miles of this area contributes to surface runoff.

The Arikaree River flows northeast across the southeast corner of Wray no. 4 quadrangle and joins the Republican River east of the area described in this report. Intermittent streams flow into the Arikaree River from the northwest and the southeast.

Many wells, pumped by windmills, obtain potable water from gravel at depths of 50 to 150 feet in quantities adequate for domestic and stock use. North of the river, water is obtained from the gravel of the Grand Island formation at depths of 50 to 75 feet or from gravel of the Ogallala formation at depths of 50 to 150 feet. South of the Republican River, it is necessary to drill much deeper for water because the loess is very thick and the gravel of the Ogallala formation is the only aquifer. There is little or no Grand Island formation south of the Republican River. Near Wray and Laird, wells are drilled in valley fill. Locations of wells are shown on the geologic map and logs are given in an appendix at the end of the report. The water table intersects the surface in the valleys near the heads of the Republican River and Chief Creek. Springs and many seeps occur in gullies along the contact of the Pierre and Ogallala formations.

Many intermittent ponds form in slight surface depressions in the loess. Because the loess lies above the water table in this area, it does not yield water to wells.

The sand hills north of the Republican River act as reservoirs, because the permeability and porosity of the sand make possible the accumulation and temporary storage of large amounts of water. Seepage of rain water into the dunes prevents high surface runoff. The sand is composed of rounded grains, 80 percent of which are between 0.1 and 0.5 millimeters in diameter. Because of the uniformity of size and the rounded shape of the grains, the pore space is large, and the capacity for water storage is great. Some of the water stored in the sand dunes seeps downward into the Grand Island formation and the gravels of the Ogallala formation, which are the main aquifers in the area. The water that seeps laterally through the sand accumulates as temporary ponds in the depressions between the dunes; many of these ponds are utilized as stock wallows and watering places. Much of the water is discharged to the Republican River by lateral seepage through the sand hills.

At present, irrigation is relatively unimportant in the Wray area. In 1944 only 1,175 acres of land were irrigated in Yuma County (Crampon, 1949, p. 4). Most of the irrigated land lies in the valley of the Republican River east of Wray, where the main irrigation channel, the Haigler ditch, runs from the Republican River and flows approximately parallel to the river eastward out of the area.

CLIMATE AND VEGETATION

The climate of the Wray area is semiarid; the average precipitation is 18.29 inches a year and is heaviest from April to August, inclusive. The region has a typical inland climate, with wide seasonal variations in temperature. The average yearly temperature is 51° F.; the highest recorded temperature is 108° F., and the lowest —32° F. During the summer months, temperatures higher than 100° F. are not unusual; occasional dust storms and rare violent thundershowers do nothing to alleviate the heat. Residents of the area work in their fields during the early morning and late afternoon; they make no attempt to work out-of-doors during the hot part of the day. In the winter, snow covers the area, and sub-zero temperatures continue for long periods of time. The prevailing wind is from the northwest, although in the summer months the winds shift and blow from the southeast. The average wind velocity is 11 miles per hour; winds of higher velocities produce dust storms in the summer and drifting snow in the winter (U. S. Weather Bureau, Denver, Colo., personal communication).

Trees are scarce in the area except in the town of Wray, along streams, and in ravines containing intermittent streams. The rolling uplands in the southern part of the area, where not farmed, are covered by low grasses, chiefly buffalo, grama, needle, and wheatgrass. Except for small blowout areas, the surface of the sand hills and the lowlands between them are covered with sparse vegetation, consisting mostly of coarse grass, such as redfieldia and stipa, sage, yucca, sand burrs, and a few cacti.

CULTURE

The town of Wray, the seat of Yuma County, is located almost in the center of the Wray area. The town lies on the flat bottom land of the Republican River, and it is bordered on the south by steep cliffs which rise as much as 150 feet above the valley floor. Although most of the Wray area is sere and brown during the summer months, the town of Wray, with its green lawns and trees, is cool and pleasant in appearance. Wray is the largest community in the area; its population was reported to be 2,061 in the 1940 census. The town of Eckley, population 358, is 14 miles west of Wray and 1 mile north of U. S. Highway 34 (the major east-west route through the area). Two small unincorporated communities are on U. S. Highway 34: Laird, 6 miles east of Wray, and Sanborn, 13 miles east of Wray. The rest of the area is sparsely populated.

Dry-land farming and stock raising are the principal industries in the region; in 1939 approximately 60 percent of persons 14 years of age or older were employed in agriculture in Yuma County (Bur. Census 1940, p. 742). The value of farm crops in Yuma County in 1945 was $2,619,410; sales of livestock and livestock products reached $3,808,324 (Bur. Census, 1945, p. 162). Wheat, hay, corn, rye, and millet are grown on the rolling uplands south of the valley of the Republican River. Hay, corn, melons, alfalfa, and truck crops are grown in the stream valleys; in the flat areas between the sand hills, corn, wheat, alfalfa, and sweet clover are cultivated. The grass-covered uplands and the sand hills are used as grazing land.

Good production is obtained from crops grown on the loess uplands, in the valley bottoms, and in the flats between the sand hills. The soil at the edges of the flats, close to the sand hills, is too sandy to support crops; when the natural vegetation is removed by plowing, the fields may become areas of active deflation, because the wind and rain quickly erode the sandy soil. During the 1930's many persons attempted to farm these sandy, marginal lands; the many small abandoned farmhouses in the Wray area are mute evidence of their failure. Some of the fields that were cultivated 15 years ago have not yet been recovered by vegetation.

DESCRIPTIVE GEOLOGY

GENERAL RELATIONS

The Wray quadrangles are on the eastern flank of the Julesburg Basin, which lies in a great structural trough formed by the down-warping of Cretaceous and older formations during the Laramide revolution. Flat-lying Cenozoic sediments were deposited on the eroded surface of the Cretaceous and older rocks. The great sub-surface structural trough extends along the foothills of the Rocky Mountain Front Range from southern Wyoming to southern Colorado, and eastward into eastern Wyoming, western Nebraska, and northwestern Kansas. The basin is asymmetrical, with a steeply dipping western side and a gently dipping eastern side. Near the western edge of the basin are many minor folds and flexures, some of which contain commercial quantities of oil or gas. South of the Wray area, on the eastern flank of the basin, is the Wray gas field on a small flexure called the Beecher Island dome.

All formations that crop out in the Wray area are semiconsolidated to unconsolidated sediments and apparently are horizontal except for slight initial dip. No subsurface data are available and structure at depth could not be determined. The oldest formation exposed in the Wray quadrangles is the Pierre shale of Late Cretaceous age. The Pierre shale is unconformably overlain by the Ogallala

TABLE 1.—*Geologic map units in the Wray area*

System	Series	Map unit	Character [1]	Estimated maximum thickness (feet)	Construction materials
Quaternary	Recent	Alluvium	Unconsolidated silt, sand, and gravel.	(?) 30	
	Pleistocene and Recent.	Sand Hills formation.	Pale yellowish-brown (10 YR 6/2), wind-deposited quartz sand.	100	Blending sand mineral filler, plaster sand.
		Valley fill	Sandy silt, dark-gray (N 3) to light-gray (N 7); sand, cross-bedded with some lenses of gravel.	75	Road metal, blending sand, binder, fine aggregate.
		Sandy silt and clay.	Yellowish-gray (5 Y 8/1) to pale yellowish-brown (10 YR 6/2), calcareous sandy silt and clay.	35	Binder.
	Pleistocene	Peorian loess	Wind-deposited silt (loess), calcareous, yellowish-gray (5 Y 7/2).	130	Mineral filler.
		Unconformity			
	Pleistocene	Grand Island formation.	Sand and gravel, loosely consolidated, calcareous, pale reddish-brown (10 R 5/4) to light-gray (N 7).	20	Aggregate, road metal, mineral filler.
		Unconformity			
Tertiary	Pliocene	Ogallala formation.	Sand, gravel, and silt, cemented to varying degrees with calcium carbonate; some lenses of limestone, volcanic ash, clay.	220	Aggregate, polishing powder, mineral filler.
		Unconformity			
Cretaceous	Upper Cretaceous.	Pierre shale	Clay shale, thin-bedded, pale-olive (10 Y 6/2) to dark yellowish-orange (10 YR 6/6). Contains thin lenses of bentonite and selenite.	[2] 1,500+	

[1] Color terms, with the exception of terms used in soil descriptions, are taken from the Rock-color chart, distributed by the National Research Council, Washington, D. C., 1948. The generalized soil descriptions in this bulletin are based on information from an unpublished report by the Soil Conservation Service and the Colorado Agricultural Experiment Station; the soil color terms used in this bulletin are the same as those used in the unpublished report. Numbers given after soil color indicate that the term is a Provisional Soil Survey color name, based on Munsell color charts.

[2] 100 feet exposed.

formation of Pliocene age, which is in turn overlain by the Pleistocene Grand Island formation. Peorian loess, Pleistocene and Recent sandy silt and clay, late Pleistocene to Recent dune sand, and Recent alluvium are also exposed. (See table 1.)

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

PIERRE SHALE

The Pierre shale, a pale-olive (10 Y 6/2) to dark yellowish-orange (10 YR 6/6) clay shale containing some selenite and bentonite, is the oldest formation exposed in the Wray area. It is marine in origin and Late Cretaceous in age.

Extent and distribution.—The Pierre shale is exposed in Wray no. 4 quadrangle and along the eastern edge of no. 3 quadrangle. It crops out in the sides of southward-heading ravines on the south side of the Republican River and in northwestward-heading ravines on the northwest side of the Arikaree River. Only about 100 feet of Pierre shale is exposed. Wells drilled in the Beecher Island Dome south of the Wray area show the total thickness of the Pierre shale to be about 1,500 feet; one well drilled in the Wray area (see well log no. 116) records shale to a depth of 3,275 feet, but the formations penetrated by this well could not be determined because the log for the upper 2,410 feet is missing (Barb, 1946, pp. 428–429). This seems to indicate that the Pierre shale may be more than 1,500 feet thick. The Pierre shale is unconformably overlain by the Pliocene Ogallala formation. (See fig. 3.)

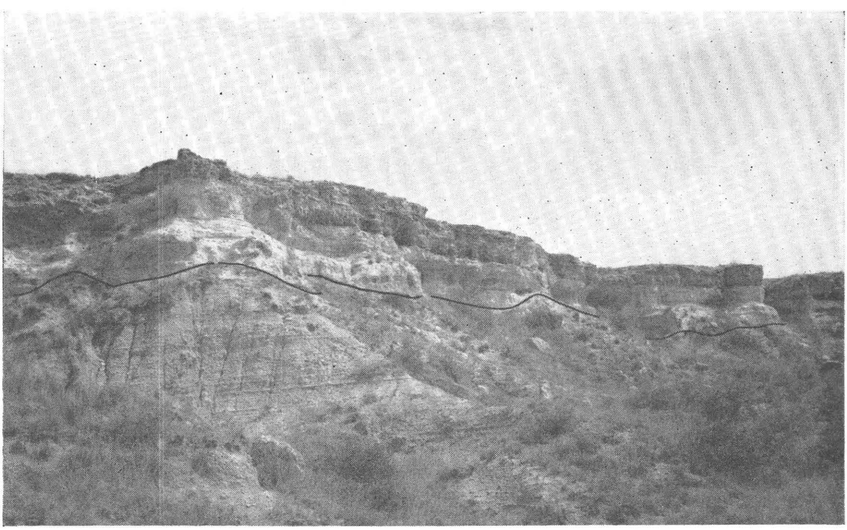

FIGURE 3.—Contact between Pierre shale and Ogallala formation (W½ SE¼ sec., 2 T. 1 N., R. 45 W).

Previous work.—The Pierre shale was first described and named the Fort Pierre group in 1861 by Meek and Hayden (1861, pp. 419–424). The Pierre shale is the lowest formation in the Cretaceous Montana group, which was named and described in 1889 by Eldridge (1889, p. 93). In 1928, Mather, Gilluly, and Lusk (1928) described several members of the Pierre shale in northeastern Colorado; in 1931, Elias (1931, pp. 43–131) made tentative correlations between these members and similar beds in the Pierre shale of Wallace County, Kans., and Beecher Island, Colo. (south of the Wray area). Only a very small amount of Pierre shale is exposed in the Wray quadrangles, and although the lithology is similar to that of the shale near Beecher Island, no exact correlations could be made between the shales in the two areas. The shale in the Wray area could not be divided into members.

Lithology.—The Pierre shale exposed in the Wray area is thin-bedded, pale-olive (10 Y 6/2) to dark yellowish-orange (10 YR 6/6) clay shale. It contains thin iron-stained beds and a few thin, lenticular beds of bentonite. Where it is exposed in ravines in the southeastern corner of the area, the Pierre shale contains many thin lenses and seams of gypsum (selenite and a fibrous variety), from one-eighth inch to 1½ inches thick, which weather out on the surface as aggregates of crystals. In the SW¼ sec. 8, T. 1 N., R. 42 W., the shale contains a few impure, white (N 9) to yellowish-gray (5 Y 7/2) bentonite seams, from one-quarter inch to 6 inches thick. These seams are remnants of volcanic ash falls. The purest bentonite, consisting of fine shards of white (N 9) volcanic ash partly altered to clay, crops out in a bed about 6 inches thick. The other seams, which are from one-quarter inch to one-half inch thick, consist of coarse, only slightly altered glass shards mixed with grains of fine sand and silt.

Fossils and age.—The only fossil found in the Pierre shale is one specimen of *Baculites* sp. The shale could not be correlated with any previously described members of the Pierre; consequently, it was mapped as undifferentiated Pierre shale of Late Cretaceous age.

Soils.—The soil descriptions in this bulletin are based on information obtained from an unpublished report by the Soil Conservation Service and the Colorado Agricultural Experiment Station. The distribution of the soils described in this report is shown on an accompanying field map, and by comparing this map with the geologic map of the Wray area, one or more of the described soils was correlated with each geologic map unit. Generalized soil profiles and characteristics for each map unit were condensed from the descriptions of the one or more soils thus correlated with the geologic map unit.

The extremely fine-textured soils developed from the Pierre shale are plastic and sticky when wet. Both the soil and the parent material shrink greatly while drying; the dry soil is hard and tough, and has a blocky texture. A generalized soil profile (top to bottom) follows:

1. Dark-gray (5.0 Y 4/0.5 dry) to dark olive-gray (5.0 Y 3/2 moist) heavy clay; hard, tough, with medium-blocky structure when dry; plastic and sticky when wet; 4 to 10 inches thick.
2. Olive-gray (5.0 Y 5/1 dry) to dark olive-brown (2.5 Y 4/2 moist) heavy plastic clay; may have irregular blocky structure; calcareous in most places; may contain gypsum crystals; 4 to 10 inches thick.
3. Partly weathered gray (5.0 Y 5/0.5) or olive-brown massive to slightly blocky clay or clay shale; calcareous; may contain gypsum crystals; 6 to 12 inches thick.
4. Unaltered parent shale.

The soil may be developed on a nearly level or steeply sloping surface. Surface runoff is medium to high, and permeability is very low. In some places wheat, other small grains, and forage are grown on the soils developed from the Pierre shale, although the average yield is low. Rough areas are used for grazing. Selenium in the vegetation grown on some of these soils is poisonous to livestock, and appreciably reduces the value of the land.

TERTIARY SYSTEM

PLIOCENE SERIES

OGALLALA FORMATION

The Ogallala formation of Pliocene age is exposed as bluffs along the south side of the Republican River. Its maximum estimated thickness is 220 feet, and it has an estimated initial dip of 12 feet to the mile. The formation unconformably overlies the Pierre shale.

Lugn (1939) has suggested that the formation be given the status of a group, divided into four formations distinguished by lithology and fossil assemblage. Because the Ogallala formation in the Wray area could not be divided on the basis of either lithology or fossil content, it is mapped as a single formation.

The bulk of the Ogallala formation consists of sand and silt cemented with calcium carbonate; the degree of cementation varies laterally and vertically. The formation crops out as a succession of alternating ledges and slopes called "mortar beds"; none of the beds can be traced more than a few hundred feet. The only marker bed in the formation is the capping layer of algal limestone.

Extent and distribution.—Near the town of Wray, the Ogallala formation forms prominent cliffs along the south side of the Republican River and in ravines of southward-heading streams tributary to the valley of the Republican River. In most places on the north side of the Republican River valley, the formation is covered by dune sand or by Pleistocene sandy silt and clay; south of the Republican River, it is mantled by Peorian loess. The greatest thickness of the Ogallala formation observed in one continuous vertical exposure is 81 feet; the base of the formation does not crop out at this place. Portions of the section of the Ogallala formation are exposed in various places; some exposures include the basal conglomerate and some include the capping algal limestone, but no single complete section including both capping and basal beds was found. The maximum thickness of the formation in this area is estimated to be 220 feet. East of Wray, the Ogallala formation forms low bluffs and small outliers, but erosion has completely removed the formation near the Colorado-Nebraska boundary.

Previous work.—The Ogallala formation was first named and defined by Darton (1899) who tentatively assigned it to the Pliocene epoch. Later, Darton (1920) wrote that the alternating mortar beds and fine-grained sediments of the Ogallala formation appear to have been deposited by streams in Pliocene and late Miocene time. Elias (1931) described the Ogallala as consisting of buff to pink unsorted sand and gravel, usually mixed in varying proportions with fine sand or silt, containing light-green and reddish-brown clay beds in the lower part of the formation and lenses of white and pink limestone in the middle and upper part. Hesse (1935) assigned the Ogallala formation to the Miocene and Pliocene, on the basis of the vertebrate fossils; Elias (1935) established stratigraphic zones in the Ogallala formation by the use of fossil plants, and correlated the plant zones with already described mammalian zones of known age. In 1936, Lugn (1939), working with other geologists of Kansas and Nebraska, redefined the Ogallala formation and elevated it to the status of a group consisting of four formations. This division of the Ogallala formation was based not only on lithology, but also on fossil evidence. At that time the Ogallala group was tentatively assigned to the Pliocene epoch. A brief summary of Lugn's subdivision of the Ogallala formation is given below.

The oldest of Lugn's subdivisions is the Valentine formation. It consists of fine gray unconsolidated sands below the typical mortar beds of the Ogallala and below the zone containing the fossil seed *Krynitzkia coronoformis* Elias. The mortar beds of the Ogallala

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group overlying the Valentine formation are called the Ash Hollow formation by Lugn. The formation consists of gravel, sand, silt, and fine sandy clay, which are indurated in varying amounts. The lowest bed of the Ash Hollow formation contains the *Krynitzkia coronoformis* Elias seed zones, and the rest of the formation includes most of the *Biorbia fossilia* seed zone described by Elias. The Ash Hollow also contains several vertebrate faunal zones. Above the mortar beds of the Ash Hollow is the formation called the Sidney gravel, which consists of sand and gravel ranging in size from fine sand to pebbles and cobbles 4 to 6 inches in diameter. It includes the upper part of the *Biorbia fossilia* seed zone. The Sidney gravel is irregular in thickness and is absent in some places. The youngest formation of the Ogallala group is the Kimball formation, which consists of silt, clay and fine sand partly cemented with calcium carbonate. This formation contains the fossil seeds *Echinochloa* n. sp., *Panicum elegans* Elias, and *Biorbia fossilia*. A pinkish, banded, pisolitic limestone, which Lugn believes to be identical to the "algal limestone" described by Elias (op. cit., 1931), is the uppermost bed of this formation.

In the Wray area, no beds are exposed which correspond in lithology to the Valentine formation described by Lugn. At the base of the Ogallala formation is a cross-bedded, calcium carbonate-cemented gravel and conglomerate which grades upward into the mortar beds section which corresponds to the Ash Hollow formation as defined by Lugn. No gravel corresponding to the Sidney gravel is exposed in the Wray quadrangles, and the Kimball formation can be distinguished only in the few places where the capping algal limestone crops out. Although the general lithology of the Ogallala formation is similar to that described by workers in other areas, the most striking feature of the Ogallala formation in the Wray area is the discontinuity of beds. This characteristic makes it very difficult to obtain a lithologic correlation of the Ogallala formation near Wray with the formations described by Lugn in Nebraska. Elias (1942) correlated Lugn's subdivisions with fossil seed zones in the Wray area. The correlation is based on a section measured about a quarter of a mile east of the town of Wray. However, no fossil seeds were found by the writers which would enable them to make similar correlations; therefore the Ogallala formation in the Wray quadrangles is mapped as a single unit.

Lithology.—The base of the Ogallala formation is a cross-bedded, calcium carbonate-cemented gravel and conglomerate which grades upward into the mortar beds. The mortar beds consist of sand and silt cemented with calcium carbonate, and they crop out as alternating ledges and slopes. Because the degree of cementation varies laterally as well as vertically, none of the beds can be traced more than a few hundred feet. A marker bed of banded, pisolitic algal limestone is the capping layer of the formation.

A gravel and conglomerate bed forms the basal member of the Ogallala formation in the Wray area. The maximum thickness of the conglomerate is 10 feet, but it varies in thickness and is absent in many places. The material varies from moderately well-cemented conglomerate to unconsolidated gravel, which is mixed with silt, clay, and sand in most places. Channeling and cross-bedding are common. (See fig. 4.) The cementing material is calcium carbonate; the degree of cementation varies laterally and vertically. The moderately well-

FIGURE 4.—Cross-bedded conglomerate at base of Ogallala formation (SW¼ sec. 8, T. 1 N., R. 42 W.).

cemented lenses form pronounced ledges, but the conglomerate is porous in most places and may be broken easily with a geologic pick. The gravel and conglomerate beds are light olive gray (5 Y 6/1) on weathered surfaces and grayish orange (10 YR 7/4) to light brown (5 YR 6/4) on fresh faces. The beds contain pebbles and cobbles as great as 1 foot in diameter, of feldspar, limestone, quartz, basalt, granite, diorite, and quartzite, as well as limonite and clay balls. Quartz and feldspar predominate. The pebbles of feldspar and other igneous minerals and rocks are subangular to round; the pebbles of limestone and other soft rocks are angular. Following is a section measured in the SW¼ sec. 8, T. 1 N., R. 42 W., which includes the upper part of the Pierre shale, the basal portion of the Ogallala formation, and Peorian loess.

Section of Pierre shale, Ogallala formation, and Peorian loess in SW¼ sec. 8, T. 1 N., R. 42 W

	Feet
Peorian loess:	
Loess, yellowish-gray (5 Y 7/2)	5. 0
Loess, yellowish-gray (5 Y 7/2), contains pebbles from the Ogallala formation	2. 0
Total of Peorian loess	7. 0
Unconformity.	
Ogallala formation:	
Silt, limy; shaly parting; grades into marl, very pale-orange (10 YR 8/2) to white (N 9)	6. 0
Silt, slightly calcareous; indurated, very pale-orange (10 YR 8/2)	3. 0
Silt, sandy; contains some calcium carbonate; grayish-orange (10 YR 7/4)	. 5
Conglomerate; moderately well-cemented, some limestone lenses; very pale-orange (10 YR 8/2); gray-weathering	8. 0
Gravel; unconsolidated; cemented in patches	8. 0
Conglomerate; calcareous cement; loosely consolidated at bottom; cross-bedded; ledge-forming; contains pebbles and cobbles from one-quarter inch to 1 foot in diameter; pebbles are feldspar, limestone, quartz, basalt, granite, diorite, and clay balls; feldspars and granites subangular to rounded; limestone angular	5–10. 0
Total of Ogallala	30. 5–35. 5
Unconformity.	
Pierre shale:	
Shale, fissile, dark yellowish-orange (10 YR 6/6); some 1-inch layers of bentonite	15. 0
Total of section	52. 5–57. 5

The bulk of the Ogallala formation consists of sand and silt cemented with calcium carbonate. The degree of cementation varies from place to place, and the formation crops out as a succession of alternating ledges and slopes. The most distinctive features of the outcrops of the Ogallala formation are the ledges of mortar beds; the ledges are formed by beds of poorly sorted sand, pebbles, and silt cemented with calcium carbonate and commonly case-hardened. These cemented beds have a mortar-like appearance and feel rough to the touch; hence the name mortar bed. The mortar beds are mentioned as a typical feature of the lithology wherever the Ogallala formation has been described. Following is a section measured in a railroad cut in sec. 31, T. 2 N., R. 44 W., showing the typical alternation of ledge- and slope-forming beds. (See fig. 5.)

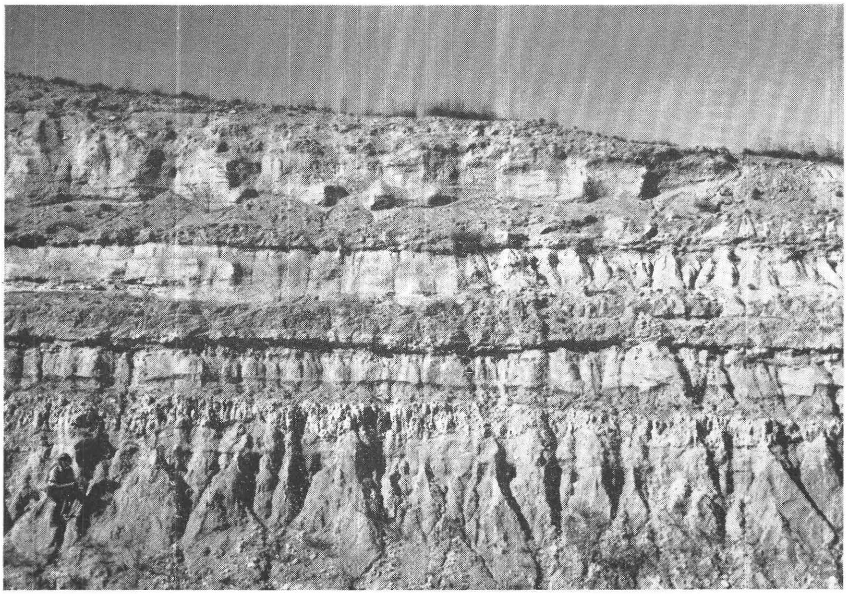

FIGURE 5.—Ledges and slopes of the Ogallala formation in railroad cut (NE¼ sec. 31, T. 2 N., R. 44 W.), showing typical lensing and alternation of consolidated and unconsolidated "mortar beds."

Section of Ogallala formation exposed in railroad cut in sec. 31, T. 2 N., R. 44 W.

	Feet
Sandstone, calcareous; grayish orange-pink (5 YR 7/2), gray-weathering; friable; case-hardened; bluff-forming	10. 50
Sandstone, calcareous; grayish orange-pink (5 YR 7/2), friable; contains pipes and stringers of white calcium carbonate; interbedded with marl, impure and porous, white (N 9) to grayish orange-pink (5 YR 7/2)	4. 50
Sandstone, calcareous; white (N 9) to grayish orange-pink (5 YR 7/2); friable and porous	1. 25
Sandstone; pinkish-gray (5 YR 8/1); friable, very loosely consolidated; some calcium carbonate; ledge-forming; grades into underlying layer	2. 00
Sandstone; light greenish-gray (5 GY 8/1); friable, loosely consolidated	2. 00
Sand; grayish orange-pink (5 YR 7/2); slope-forming	1. 00
Sand; grayish-orange (10 YR 7/4); slope-forming	3. 00
Sandstone, calcareous cement; coarse with some conglomeratic lenses; porous in places; very pale-orange (10 YR 8/2); ledge-forming	1. 00
Sand; very pale-orange (10 YR 8/2); some calcium carbonate stringers	4. 50
Sandstone; calcareous cement; silicified at top	2. 50
Sandstone, argillaceous; very pale-orange (10 YR 8/2); loosely consolidated	1. 00
Sandstone, calcareous; gray-weathering; case-hardened	1. 50
Sandstone, shaly; very fine-grained; grayish-orange (10 YR 7/4); friable	1. 00
Marl, impure; white (N 9); punky, soft, breaks into small chunks	4. 50
Sandstone; fine-grained, loosely consolidated; grayish-orange (10 YR 7/4); slightly gummy; slope-forming	5. 00
Clay, shaly; calcareous; white (N 9) to pinkish-gray (5 YR 8/1)	8. 00
Sandstone; fine-grained, loosely consolidated; grayish-orange (10 YR 7/4); slightly gummy	3. 00
Total of section	56. 25

The mortar beds contain very few true limestones. One small ledge of dense, fine-grained white limestone crops out in the northeast corner of sec. 16, T. 1 N., R. 44 W. This ledge is 3 feet thick and contains many worm holes and external molds of small gastropods identified by Elias (personal communication, March, 1950) as *Gryaulus* sp. and *Pseudosuccinea* cf. P. *columella* (Say).

The Ogallala formation in this area contains one bed of volcanic ash 1 to 10 feet thick. It is best exposed where it crops out in the NE¼ sec. 16, T. 1 N., R. 44 W., about 26 feet below the white limestone described in the preceding paragraph. The fine, white, unconsolidated ash, which stands in vertical cuts (see fig. 6), is composed of about 95 percent slightly altered glass shards, with an index of refraction of 1.497. The following section, measured in the Ogallala formation in the NE¼ sec. 16, T. 1 N., R. 44 W., includes the volcanic ash and the limestone layer containing gastropods.

Section of the Ogallala formation in NE¼ sec. 16, T. 1 N., R. 44 W.

	Feet
Limestone, impure; white, (N 9)	2. 0
Conglomerate containing pebbles of quartz, feldspar, and calcareous sandstone from one-eighth inch to 2 inches in diameter; contains sandy lenses; cemented with calcium carbonate; grayish orange-pink (5 YR 7/2)	7. 0
Sandstone, calcareous; fine-grained, poorly cemented; very pale-orange (10 YR 8/2) to grayish-orange (10 YR 7/4); very friable	3. 5
Sandstone, calcareous; fine-grained; hard	1. 5
Sandstone, calcareous; shaly in places; very pale-orange (10 YR 8/2); friable	3. 5
Sandstone, calcareous; contains aggregates of light greenish-gray (5 GY 8/1) clay; porous; gray-weathering	5. 0
Sandstone, calcareous; very pale-orange (10 YR 8/2) to grayish-orange (10 YR 7/4), gray-weathering; middle 3 feet loosely consolidated; upper 7 feet contains calcareous nodules and pipes; ledge-forming	12. 5
Limestone; fine-grained; hard; white (N 9); silicified in places; contains holes and many casts of small gastropods	3. 0
Sandstone, calcareous; contains worm (?) holes	3. 0
Marl; porous, fine-grained, yellowish-gray (5 Y 8/1); contains numerous grains of light greenish-gray (5 G 8/1) clay; upper 3 feet less porous, contains less clay	9. 0
Silt, sandy; calcareous; slope-forming	2. 0
Sandstone, calcareous; coarse-grained, porous; white (N 9)	2. 0
Marl, sandy; grayish-orange (10 YR 7/4)	1. 5
Sandstone, calcareous cement; fine-grained; white (N 9)	8. 5
Volcanic ash; very fine; white (N 9) to very light-gray (N 8); top 4.5 feet contains cemented, impure nodules of ash	10. 0
Sandstone, fine-grained; grayish-orange (10 YR 7/4); friable	2. 0
Total of section	76. 0

Lenses of porous, milky-white, brittle chert, mottled with black splotches and brown iron stains, are found throughout the mortar beds,

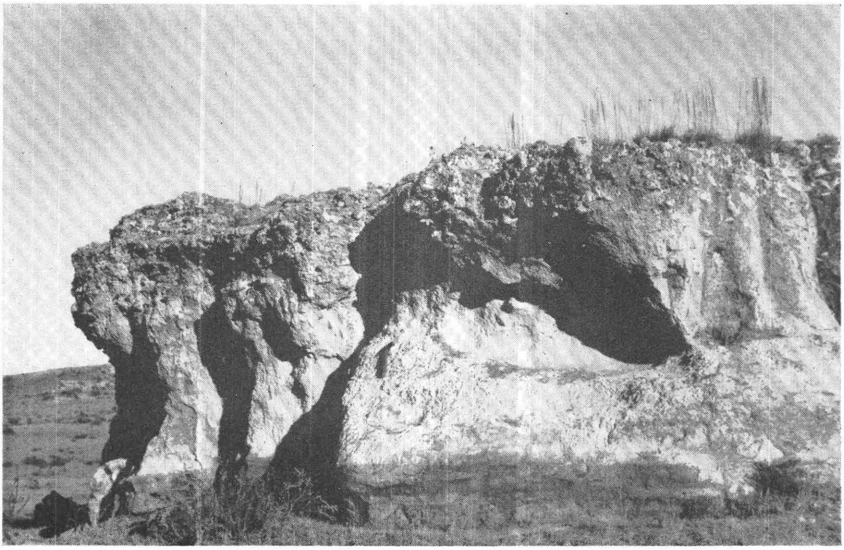

FIGURE 6.—Volcanic ash of the Ogallala formation exposed in sec. 16, T. 1 N., R. 44 W.

and in many places sandstones of the formation are cemented with secondary silica. Although the chert lenses and silica-cemented sandstones are rarely more than 1 foot thick, they are resistant to erosion and in many places are the capping beds of the outcrops of the Ogallala formation.

Above the mortar beds is a thin and persistent limestone bed. In its most distinctive facies it is very pale orange (10 YR 8/2) to grayish orange (10 YR 7/4), compact, dense, and contains light-brown (5 YR 6/4) pisolitic, concentric, and wavy-banded structures. Wherever this bed crops out in the Wray quadrangles it marks the top of the Ogallala formation. This capping layer, which averages about 2 feet thick, is the only marker bed in the formation. A similar bed at the top of the Ogallala formation was found by Elias (1931, pp. 131–163) in Wallace County, Kans. He described it as follows:

The pink concentrically banded limestone usually does not outcrop as a solid ledge, but is broken into irregularly oval or angular and somewhat flattened cobbles a few inches to a foot or more in horizontal diameter. The texture of the bed may be called irregularly pisolitic, the limestone being traversed by a very fine more or less concentric rhythmic banding. The fine banding presents an alternation of creamy, light-brown, brick red, and otherwise shaded reddish-brown irregularly concentric bands, the cores of which and the matrix between the irregularly oval "ovulites" are usually colored in nearly uniform light creamy or pinkish shades. The rock is usually full of scattered grains of colorless quartz and pink feldspar, the size of which ranges from tens of microns to a few millimeters. Very rarely much larger pebbles of quartz are observed in the rock. Some of the sand grains are found in the center of the smaller and more regular pisolitic "ovulites," but the vast majority of these grains have no relation to the banding at all and are scattered uniformly through the rock. Many of the larger loops of banding embrace groups of smaller concentric structures. A few fragments, also, with nearly parallel banding have an enveloping crust of fine concentric banding. This and other examples of interrupted and resumed growth are fairly frequent. The thin section reveals a cryptocrystalline structure, the banding of which is due to the zonal arrangement of nearly opaque calcium carbonate, a little more crystallized and more transparent buff-colored bands of the same substance and occasionally still more transparent layers of the same carbonate with a faint radial (transverse) structure. The first two kinds of bands are not sharply separated, the nearly opaque substance presenting lobate and digitate outgrowths into the lighter bands. Locally there are much thinner and closer spaced brick-red bands of iron oxide and buff-colored calcium carbonate. In the broader bands may be noticed a few small spherical bodies with a comparatively thin outer zone made of a mosaic of comparatively coarse-grained colorless calcite, much like the walls of the hollow spheres representing the individual cells of *Chlorellopsis coloniata* Reis, the microscopic alga of the Green River formation reefs. Some of the spherical bodies from the Ogallala rock are hollow also. The more important difference between the spheres from the limestones of the two formations is the smaller diameter of the spheres from the Ogallala.

Elias has named the alga *Chlorellopsis bradleyi.*

In megascopic appearance, the grayish-orange (10 YR 7/4), concentrically banded limestone at the top of the Ogallala formation in the Wray area is almost identical with that of the algal limestone described by Elias (see fig. 7). Thin sections of the Wray area limestone show the same concentric banding as that in the limestone described by Elias. The limestone capping the Ogallala formation in the Wray

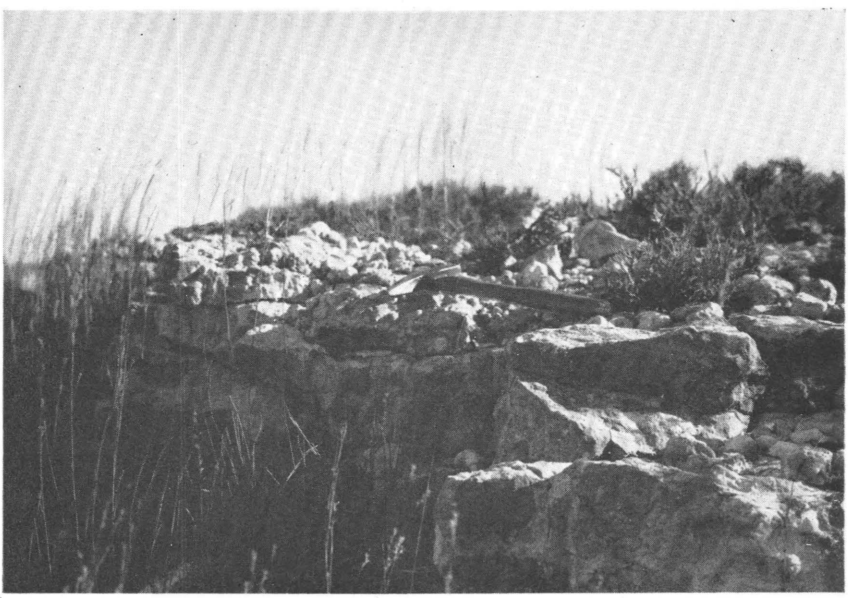

FIGURE 7.—Exposure of typical "algal limestone" of the Ogallala formation in the NE¼ sec. 30, T. 1 N., R. 44 W., showing nodules and banding.

area has been identified by Elias (personal communication, March, 1950) as *Chlorellopsis bradleyi*. In Nebraska, the algal limestone is at or near the top of the Ogallala formation and was described by Lugn (1939) as part of the Kimball formation.

Two sections showing typical algal limestone and underlying beds at the top of the Ogallala formation follow:

Section of the Ogallala formation in the center of the north half of sec. 36, T. 1 N., R. 45 W.

	Feet
Limestone, "algal bed"; very pale-orange (10 YR 8/2) with concentric light-brown (5 YR 6/4) banding; algalike structure; pisolitic	2–3. 0
Silt, sandy; light-brown (5 YR 6/4); case-hardened in places; contains chunks of sandy limestone which weather out on the silt slope	12. 0
Sandstone, calcareous; grain size variable with some gravelly lenses; pale greenish-yellow (10 Y 8/2) on fresh face; contains thin calcareous pipes, opalized in the center; alternating friable and massive layers form three prominent ledges with slopes between them	16. 0
Sandstone, calcareous and conglomeratic; very pale-orange (10 YR 8/2) on fresh face weathering light olive-gray (5 Y 6/1); ledge-forming	9. 0
Sandstone, calcareous; marly with shaly partings; interbedded white (N 9) and very pale-orange (10 YR 8/2); very friable	2. 5
Sandstone, calcareous; varies to sandy limestone; white (N 9) to very pale-orange (10 YR 8/2); very hard; ledge-forming	2. 0
Sandstone, more limy and friable than above bed; contains some chert nodules; white (N 9) with some very pale-orange (10 YR 8/2) lenses	2. 0
Marl; interbedded very pale-orange (10 YR 8/2) to white (N 9); friable	2. 0
Limestone, argillaceous; contains limestone nodules which weather out	2. 0
Sandstone, calcareous; very loosely consolidated	4. 0
Total of section	53. 5–54. 5

Section of the Ogallala formation in the NE¼ sec. 30, T. 1 N., R. 44 W.

	Feet
Limestone, "algal bed"; grayish-orange (10 YR 7/4); hard, dense, pisolitic	2. 0
Limestone, sandy; white (N 9) to grayish-orange (10 YR 7/4); irregularly cemented; contains thin limestone laminae; weathers to nodules	33. 5
Sand, limy; very pale-orange (10 YR 8/2) to pale greenish-yellow (10 Y 8/2); unconsolidated, with some limestone lenses	2. 5
Sandstone, calcareous; very pale-orange (10 YR 8/2); soft; case-hardened; gray-weathering	3. 5
Marl, sandy and porous; white (N 9); laminated and crumbly	1. 0
Sandstone, calcareous; medium-grained; very pale-orange (10 YR 8/2), gray-weathering; case-hardened in places; bluff-forming	9. 0
Sandstone, calcareous; very pale-orange (10 YR 8/2), gray-weathering; soft, bluff-forming; upper 2 feet harder, ledge-forming	10. 0
Limestone, sandy; white (N 9); slope-forming; slope covered with small weathered chunks of limestone	5. 0
Limestone, sandy; gray-weathering; hard, dense, ledge-forming	2. 5
Silt, sandy; soft, cemented with calcium carbonate in varying degrees; grayish-orange (10 YR 7/4)	12. 0
Total of section	81. 0

The Ogallala formation has an estimated dip to the east or southeast of 12 feet to the mile. Because no evidence of local flexures was found in the area the dip is believed to be initial rather than deformational.

Fossils and age.—No fossils were found by the writers which enabled them to date the Ogallala formation. Fragments of the carapace of a large turtle were seen, and broken mammalian bones, but none were well enough preserved for positive identification. No fossil seeds were found. Some external molds of gastropods identified by Elias as *Gryaulus* sp. and *Pseudosuccinea* cf. *P. columella* (Say) were found in limestone layers in the Ogallala. The combination of these two forms is frequently found in limestone beds throughout the Ogallala formation. The Pliocene age of the formation, assigned by other workers (Lugn, 1939) in and near the Wray area, has been accepted by the writers.

Soils.—Sandy, grayish-brown loam is developed on the Ogallala formation. Soils on nearly level or rolling uplands are 24 to 36 inches thick, but those on rough and rolling terrain, especially on eroded knobs and the sides of hills, are thin and poorly developed. A generalized profile is given below for a soil developed on a flat upland underlain by the Ogallala formation.

1. Grayish-brown (10 YR 4/1 dry), massive, noncalcareous loam; 4 to 8 inches thick.
2. Brown, massive, slightly cloddy or prismatic loam; highly calcareous; hard when dry; 6 to 8 inches thick.
3. Light-brown, light grayish-brown (10 YR 6/2 dry), light reddish-brown, or nearly white highly calcareous very fine sandy loam or clay loam; contains increasing amounts of gravel and sandstone fragments with depth; unmodified sandstone or reddish-brown clay loam or gravelly loam at depths of from 2 to 3 feet.

Internal and surface drainage is good on flat uplands; surface drainage may be excessive on steep slopes. Some wheat and corn are grown on these soils, although most of the land underlain by the Ogallala formation is used as pasture land.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

Formations of Pleistocene age in the Wray area are the Grand Island formation and the Peorian loess. The valley fill, the sandy silt and clay, and the Sand Hills formation, which are late Pleistocene and Recent in age, are discussed in a later part of this report.

The Grand Island formation, of Kansan age, unconformably overlies the Ogallala formation and is the oldest Pleistocene deposit in the Wray area. The formation consists of pale reddish-brown (10 R 5/4), cross-bedded, calcareous sand and gravel which is exposed only in pits in the northwest portion of the Wray area. The yellowish-gray (5 Y 7/2) Peorian loess overlies the Ogallala formation south of the Republican River.

GRAND ISLAND FORMATION

Extent and distribution.—The Grand Island formation does not crop out in natural exposures, and is seen only in man-made pits, which (with one exception) are in the northwest portion of the Wray area. For this reason, the Grand Island formation is not shown as a separate unit on the geologic map; instead, it is included with the overlying sandy silt and clay. The sandy silt and clay and the underlying Grand Island formation occupy the flat areas between the long, northwestward-trending sand hills of the Sand Hills formation north of the Republican River. The observed maximum thickness of the Grand Island formation is 20 feet.

Previous work.—The Grand Island formation was first named and described by Lugn, in a paper presented at the forty-fourth annual meeting of the Geological Society of America at Tulsa, Okla., in December 1931. He stated that "the Grand Island formation (Kansan), from 50 to over 100 feet thick, lies unconformably on the Fullerton bed." It is named for exposures at and around Grand Island, Hall County, Neb. Lugn (1934, 1935) further described the formation by stating that the upper 30 to 50 feet consists of fine sand, of possible eolian origin, whereas the lower part contains gravel, "and is clearly a fluvial deposit." An exposure about 120 miles east of the Wray area, 1½ miles northwest of the town of Arapahoe, is described by Lugn as "Grand Island sand and gravel, typical fluviatile material, bedded and cross-bedded, some zones contain smudges of black sooty carbonaceous material"; this is the westernmost exposure described by Lugn. The gravel of the Grand Island formation exposed in several other places in western Nebraska, is described by Lugn as "buff-pinkish" or "pink to reddish" in color; the gravel in eastern Nebraska is described as buff colored, gray, or yellowish-gray.

Because the gravel in the Wray area seems to be of the same lithology as the gravel of the Grand Island formation, and apparently is of Kansan age, it is called the Grand Island formation in this report, although the formation could not be traced from exposures in Nebraska into the Wray area.

Lithology.—The Grand Island formation consists of numerous lenses of pale reddish-brown (10 R 5/4), calcareous sand and gravel, cross-bedded in most places, containing rounded pebbles of granite, feldspar, quartz, quartzite, and sandstone, with 90 percent of the fragments from 10.0 millimeters to 0.2 millimeters in diameter. The gravel is iron-stained, and the pebbles are coated and loosely cemented with fine light-brown (5 YR 5/6) silt and calcium carbonate. Some of the gravel beds contain balls and lumps of clay and pipes and stringers of calcium carbonate at or near the top of the gravel. All the gravel beds contain large amounts of calcium carbonate near the top. (See fig. 8.) In some places the formation contains bands and lenses of gravel which are coated with a black stain. Given below are sections in two pits in the Wray area where the gravel of the Grand Island formation is exposed.

Section of Grand Island formation in NE¼ sec. 27, T. 2 N., R. 46 W., pit no. 16

	Feet
Soil, dark, sandy	0. 5
Sand, some pebbles, very calcareous; lime nodules	2. 0
Sand and gravel, pale reddish-brown (10 R 5/4), grading to silt in places; some black-coated material; some white pebbles from Ogallala formation	8. 0
	10. 5

Section of Grand Island formation in center E½ sec. 10, T. 2 N., R. 46 W.

	Feet
Soil, dark, sandy	2–3. 0
Sandy clay, loess-like, calcareous, very hard, contains root-holes	. 8
Sand, very fine, grayish-orange (10 YR 7/4)	2. 0
Gravel, reddish-brown (10 R 5/4), upper 1 foot lime-enriched, contains lime nodules and pipes	6–8. 0
Total of section	10. 8–13. 8

Fossils and age.—The gravel is believed to be the equivalent of the Grand Island formation of Kansan age. The gravels in the Wray area everywhere overlie the Ogallala formation, and underlie the Pleistocene and Recent sandy silt and the sand dunes. The gravel is exposed in a pit in the E½ sec. 10, T. 3N., R. 44 W., where it is overlain by a very fossiliferous, light olive-gray (5 Y 6/1) sand and slightly clayey silty marl. The upper part of the marl is white (N 9) and is overlain by 6 inches to 4 feet of dark yellowish-brown (10 YR 4/2) sandy soil. This dark sandy soil also fills channels cut into the marl and gravel.

The fossils found in the light olive-gray (5 Y 6/1) marl are mollusks, ostracods, and diatoms. To date, the mollusks and diatoms have not been identified. Very few Pleistocene freshwater ostracods have been described in the literature, and none of the ostracods found in the marl could be definitely identified with described forms. Some of the forms found in the marl appeared to be similar to dated, but unnamed forms in a collection loaned to the authors for study.[1] From comparison with the forms in this collection, it seems probable that the light olive-

[1] Collection of Pleistocene fresh-water ostracods from Illinois, loaned by Mary R. Hill; fossils obtained by courtesy of the Illinois State Geological Survey.

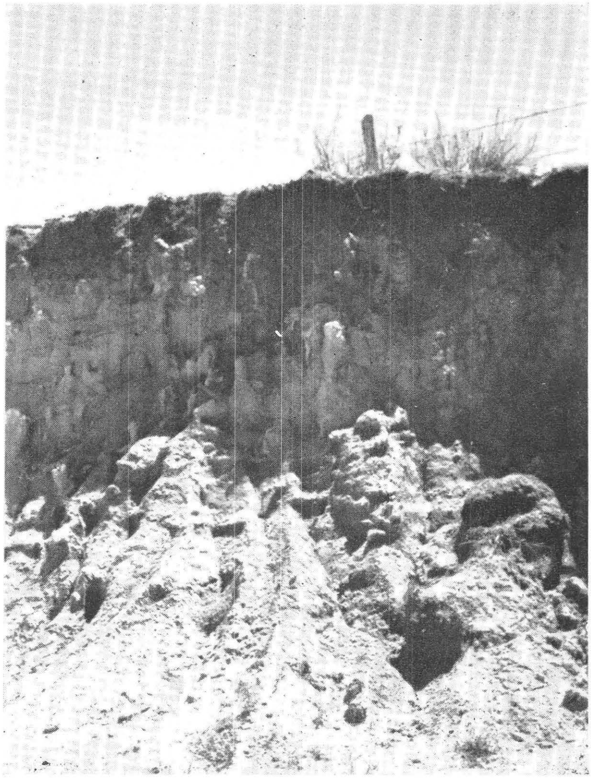

FIGURE 8.—Gravel of the Grand Island formation exposed in pit in the NW¼ SW¼ sec. 35, T. 2 N., R. 45 W., showing calcareous pipes in gravel.

gray (5 Y 6/1) marl is pre-Illinoian, probably Yarmouth, in age. The lithology of the small amount of marl exposed in this pit is similar to the lithology of the Sappa formation described by Reed (1948). The light olive-gray (5Y 6/1) marl in the Wray area is probably a remnant of the Sappa formation, and the gravel underlying the marl is probably Grand Island formation. The name "Sappa formation" now replaces the abandoned name "Upland formation" because of the physiographic implications of the term "Upland." The new type locality of the formation is in Sappa township, Harlan County, Nebr. (Reed, 1948).

PEORIAN LOESS

The Peorian loess overlies the Ogallala formation south of the Republican River; the maximum measured thickness of the loess is 85 feet. The loess is composed of fine-grained, calcareous, yellowish-gray (5 Y 7/2) silt containing many small rootlets and vertical root holes lined or filled with calcium carbonate; it stands in vertical to 45° cuts.

Extent and distribution.—South of the Republican River in the Wray area, the yellowish-gray (5 Y 7/2) Peorian loess overlies the Ogallala formation or rests directly on the Pierre shale where the Ogallala formation is missing. North of the Republican River, a small amount of loess underlying dune sand is exposed in road cuts. The maximum thickness of loess measured was 85 feet; total estimated thickness is 130 feet, as indicated in the well logs (see log 128).

Previous work.—Leverett (1898) first described a "Peorian soil and weathered zone" and stated that it was of Wisconsin age. The name Peorian loess was proposed by Kay and Leighton (1933) for "the widespread loess which lies on the Iowan drift and around its border and beneath the Mankato (late Wisconsin) drift; and in Illinois for the widespread loess which lies above the late Sangamon loess outside of Tazewell drift." In 1934 Lugn (1934) described the Peorian loess as "an almost unbroken mantle of yellowish eolian silt and clay covering 42,000 square miles of Nebraska." In Kansas, Elias (1931, pp. 178–180) described a yellow Pleistocene loess which he included with the Sanborn formation. He described it as: "* * * yellowish buff, is porous, not stratified and builds perfectly vertical cliffs * * * Toward the base it becomes sandy and grades into the gravel * * *." He says of the gravels at the base of the loess:

> The average diameter of the round stones of this gravel is from 1 to 6 inches, but in many localities there is in addition a considerable number of boulders some of which are 1½ feet in diameter, and a few boulders have been observed that were 2 or 2½ feet in diameter. These large blocks have a more or less angular shape, but their angles are smoothly rounded, and all the surface of the blocks is smooth and shiny, though at the same time irregularly pitted, as if the surface of the blocks had been fused and smoothed by lightning.

Frye and Fent (1947) reported the results of a field conference of geologists from Kansas and Nebraska, who studied the type area of the Sanborn formation. On pages 41 and 42 of this report they made the following statements regarding the Sanborn, Peorian, and associated Pleistocene deposits:

> Although no specific locality was originally designated as type section of the Sanborn, Elias stated that the exposures studied in canyons in the NW¼ sec. 20, T. 1 S., R. 41 W., northwestern Cheyenne County, Kansas, occur within this type area and constitute a satisfactory type section. In this and adjacent canyons there is exposed 170 to 180 feet of Sanborn deposits resting on Cretaceous Pierre shale. More than half of this thickness is thought to be a stratigraphic equivalent to the Peorian loess as defined by the Nebraska Geological Survey in southwestern Nebraska. Furthermore, a soil developed on material possessing the characteristics of the Loveland formation in Nebraska occurs in the lower part of the sections, in the same stratigraphic position as the Loveland soil in the Citellus zone of that state. A less well-developed soil that is found near the top of the section may be equivalent to the Brady soil which separates Peorian loess from Bignell loess in Nebraska.

Correlations of the various units exposed in the type section of the Sanborn have been made eastward across northern Kansas to the glaciated area. During the May 1947 field conference, the loesses and buried soils were traced by outcrops and auger holes southward from Jewell County across the uplands of Mitchell and Lincoln Counties to Rice and McPherson Counties.

In view of these various facts, it is proposed that the late Pleistocene loesses, associated deposits, and lateral facies generally occurring in northern and central Kansas, be classed as the Sanborn formation, and the several stratigraphic units—Loveland silt, Peoria silt, and Bignell silt—and their lateral coarse-textured facies be assigned rank as members. It is desirable to retain Sanborn as the stratigraphic unit of formational rank generally in this region because it is a convenient mapping unit, whereas the subdivisions, assigned rank as members, are difficult or impossible to delineate in sufficient detail to be usable mapping units. It also furnishes a general classification for this complex of silts and coarser clastics in parts of the region where certain correlation of the several members has not been made while allowing the classification to be brought into harmony with regions north and east of Kansas.

The type locality of the Sanborn formation (consisting predominantly of the yellowish-gray (5 Y 7/2) Peorian loess) adjoins the Wray area on the southeast; the loess of this formation extends into the Wray quadrangles. Because the gravels at the base of the Sanborn formation (described by Elias) were not found to be underlying the loess in the Wray area, and because the Loveland and Bignell loesses were not found in the Wray area, the yellowish-gray (5 Y 7/2) silt has been mapped as Peorian loess.

Lithology.—In the Wray area, the loess is a fine-grained, calcareous, porous, yellowish-gray (5 Y 7/2) silt, composed predominantly of quartz grains. It contains many small rootlets and vertical root holes lined or filled with calcium carbonate. The loess stands in vertical to 45° cuts, exhibiting columnar structure. Size analyses show that particles fall into the limited size range characteristic of loess (Russell, 1944); 64 percent of the particles are between 0.01 and 0.05 millimeters in size. On grass-covered slopes "catstep" erosion is developed where the material has slumped and formed "steps."

No Loveland loess was found in the Wray area, nor were gravels such as are described by Elias (1931, pp. 163–178) found beneath the loess. In the NW¼NW¼ sec. 13, T. 1 N., R. 44 W., a small amount of greenish-gray (5 GY 6/1) blocky clay (probably a remnant of the Sappa formation) was found directly underlying the loess; under this clay are some pebbles and boulders similar to those Elias describes. The pebbles are apparently weathered remnants of a lens of silicified material in the Ogallala formation; fresh, cherty, iron-stained pebbles and unweathered ledges of the same material are exposed beneath the weathered pebbles and the clay.

In a few places, buried soil zones overlain by a small amount of light-gray (N 7) or light olive-gray (5 Y 6/1) silt were observed near the top of the loess. These soil zones may represent the Brady soil described by Schultz and Stout (1948, p. 573), and the silt above them may be the Bignell loess (Schultz, 1945, p. 241). In most exposures, however, the silt overlying the soil zone is indistinguishable from the underlying Peorian loess. The soil zones probably represent periods of decreased eolian deposition during the Peorian age. Because the soil exposures are few and widely separated, they cannot be correlated with each other.

Fossils and age.—No fossils were found in the Peorian loess by which it could be dated. The loess has been described by other workers (Condra, Reed, and Gordon, 1947, p. 31) as middle to late Wisconsin in age.

Soils.—(Soil description based on unpublished report by the Soils Conservation Service and Colorado Agricultural Experiment Station.) The soil developed on the Peorian loess is a silt loam which in most places has a well-developed zone of lime enrichment 10 to 20 inches below the surface with unaltered parent material at a depth of 30 to 60 inches. A generalized profile of soils as developed on Peorian loess is given below:

1. Grayish-brown (10 YR 4/1 dry), friable silt loam; 1 to 12 inches thick.
2. Grayish-brown (10 YR 4/1 dry) cloddy or indistinctly prismatic heavy silty clay loam; 4 to 10 inches thick.
3. Light grayish-brown (10 YR 6/2 dry) silt or silt loam containing much lime which has been leached from above layers; 24 to 36 inches thick.
4. Unaltered parent loess.

In some places a buried surface layer of a former soil (consisting of dark grayish-brown (10 YR 3/2 dry) friable silt loam or silty clay loam of indistinctly prismatic structure) is found at depths of 15 to 22 inches, between units 2 and 3 above. The soil is developed on flat upland areas. Surface drainage is good to excessive; on steep slopes rapid runoff causes severe erosion. In most places, the soil is cultivated by dry farming methods.

LATE PLEISTOCENE AND RECENT SERIES

The late Pleistocene and Recent deposits in the Wray area are sandy silt and clay, valley fill, and the Sand Hills formation. The sandy silt and clay lies in the flat areas between northwestward-trending ridges of dune sand north of the Republican River; the valley fill, consisting of well-bedded, dark-gray (N 3) to light-gray (N 7) gravel, sand, and sandy silt, is exposed in the floodplains and terraces of the Republican River and its tributary streams. The Sand Hills formation, consisting of well-sorted, pale yellowish-brown (10 YR 6/2), unconsolidated sand, constitutes the long northwestward-trending ridges to the north of the Republican River.

SANDY SILT AND CLAY

Extent and distribution.—Calcareous sandy silt and clay overlies the Pleistocene gravels, or rests directly on the Ogallala formation where the gravels are absent. The sandy silt and clay, overlain by 3 inches to 4 feet of dark, sandy silt, lies in the flat areas between northwestward-trending ridges of dune sand north of the Republican River. The maximum thickness observed, measured in a gravel pit in the W½ sec. 13, T. 2 N., R. 44 W., was 8 feet.

Lithology.—The calcareous sandy silt and clay is yellowish gray (5 Y 7/2) to pale yellowish brown (10 YR 6/2); it stands in vertical to 45° cuts, and in some exposures it is hard and has a "blocky" fracture. It contains rootholes, lined or filled with calcium carbonate, and many thin veins of calcium carbonate. The percentage of sand, silt, and clay in this map unit varies from place to place. In some places it is almost indistinguishable from loess, but in contrast with loess, it contains many clay-sized and sand-sized particles. The bedding is indistinct or absent. A mechanical analysis of sandy silt and clay, taken from a pit in the NW¼ sec. 2, T. 2 N., R. 46 W., showed 37 percent less than 0.07 millimeter in size, and 35 percent greater than 0.4 millimeter in size. The material is highly calcareous.

The dark yellowish-brown (10 YR 4/2) sandy silt, from 3 inches to 4 feet thick, which everywhere overlies the calcareous sandy silt and clay is included in this map unit. The percentage of sand in the silt varies from place to place, and the contact of the silt and the sand hills is gradational. Although in some places the hills rise sharply from the flat silt-covered areas, in other places they slope gently and grade laterally into the silt. Mapping of the sandy silt was done on the basis of both lithology and topography.

Fossils and age.—No fossils were found in the calcareous sandy silt and clay or in the overlying dark sandy silt, and the exact age of these beds is unknown. They are younger than the underlying Grand Island formation. The calcareous sandy silt and clay, which closely resembles the loess in appearance, may be in part a valley phase of the loess and probably contains both reworked Peorian loess and sand which were laid down in stream valleys. The dark sandy silt, containing large quantities of sand undoubtedly derived from the sand hills, is probably late Pleistocene to Recent in age. Deposition of the Pleistocene and Recent sandy silt and clay was continuous from Peorian time until Recent, and the unit is contemporaneous with part or all of the Peorian loess, the valley fill, and the Sand Hills formation.

Soils.—(Soil description based on unpublished report by the Soil Conservation Service and Colorado Agricultural Experiment Station.)

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Soils developed on the sandy silt may be divided into two groups—those which are developed on windblown materials composed largely of sand, and those developed on heavier-textured, sandy, calcareous material. Given below is a generalized profile of a soil developed on sand mixed with a small amount of clay and silt.

1. Grayish-brown (10 YR 5/2 dry) loamy sand; 5 to 15 inches thick.
2. Grayish-brown (10 YR 5/2 dry) sandy loam, moderately coherent; 8 to 20 inches thick.
3. Light grayish-brown (10 YR 6/2 dry) sandy loam or fine sand; not calcareous; goes to depths of more than 4 feet.

The soil is developed on level to hummocky land. Drainage is good and precipitation is absorbed rapidly. Some of this land is farmed, but most of it is used for grazing.

A generalized profile is given below for soils developed on heavier-textured material.

1. Grayish-brown (10 YR 5/2 dry), friable sandy loam; noncalcareous, 6 to 24 inches thick.
2. Brown (10 YR 4/2 dry), sandy clay loam; 6 to 18 inches thick.
3. Very pale-brown (10 YR 6.5/3 dry) to nearly white calcareous sandy clay loam; weak prismatic structure; in some places contains calcium carbonate in soft and hard aggregations; 10 inches to several feet thick.
4. Tertiary or Quaternary calcareous sandy materials.

These soils are developed on nearly level or gently rolling plains. Permeability is high, internal drainage is good, and surface runoff is medium to low. Most of these soils produce very high crop yields by dry farming methods.

VALLEY FILL

The valley fill, which includes the flood plains and terraces of the Republican River and its tributary streams, consists of dark-gray (N 3) to light-gray (N 7) sandy silt and sand, mixed in some places with yellowish-gray loess. The fill contains a few large pockets of clean, cross-bedded sand and gravel. In most cases, the fill overlies the Ogallala formation, and grades laterally into the loess; it is probably younger than or contemporaneous with the loess. The maximum estimated thickness of the fill is 50 feet.

Extent and distribution.—The material mapped as valley fill includes the flood plain of the Republican River, well-defined terraces 40 feet above the flood plain along the sides of the valley of the Republican River, and as many as three terrace levels in ravines of tributary streams. The valley fill has been cut into terraces in many ravines which were once completely filled. Due to the fact that no continuous terrace level was discernible and the lithology and origin of all the valley fill are similar, the flood plain and all the terraces were mapped together. In some places, the Republican River flood plain slopes gradually up to the bluffs and into the ravines cut into the Ogallala formation. Where the Ogallala formation is not exposed, the fill grades imperceptibly into sand or loess. The estimated maximum thickness is 75 feet.

Lithology.—The valley fill consists of dark-gray (N 3) to light-gray (N 7) sandy silt and sand, mixed in some places with yellowish-gray (5 Y 7/2) loess, and containing pebbles from the Ogallala formation that range from one-eighth of an inch to 6 inches in diameter. The pebbles are distributed in bands and lenses, and the silt is finely laminated. Pockets of clean, highly cross-bedded sand and gravel occur in a few places in the valley fill; some of the pockets are quite large, containing over 50,000 cubic yards of sand and gravel.

Fossils and age.—The exact age of the valley fill is unknown. Many fragmental bones resembling those of bison were found in the fill, but they were too incomplete for positive identification. The fill overlies the Ogallala formation and in some places grades laterally into loess. It is probably younger than or contemporaneous with the Peorian loess, and contemporaneous with the Pleistocene and Recent sandy silt and clay deposited north of the Republican River.

Soils.—(Soil description based on unpublished report by the Soil Conservation Service and Colorado Agricultural Experiment Station.) Three distinct types of soil are developed on the valley fill. One of these is formed on the valley bottoms, another is formed on the valley sides, and a third is developed on the stream terraces. Sandy, light-colored soils are developed on the sandy alluvial sediments of the marshy bottom lands. A generalized soil profile (top to bottom) is given below:

1. Light grayish-brown (10 YR 6/2 dry) fine sand or sandy loam; may be calcareous in places; 4 to 16 inches thick.
2. Light grayish-brown (10 YR 6/2 dry), calcareous, incoherent or only slightly coherent sand or sand-gravel mixtures; rust-brown and gray stains, spots and streaks are numerous below 24 inches; 20 to 60 inches thick.

The soil is developed on level surfaces, and because the water table in most places is 3 to 5 feet from the surface, drainage is poor. Areas mantled by these soils are used for pasture land or for growing truck crops.

The soil formed on the valley sides is a grayish-brown (10 YR 4/2 dry), friable, massive, calcareous silt loam which is nearly uniform to a depth of about 3 feet. The soil is developed on moderate to gentle slopes, and drainage is good.

A generalized soil profile is given below for the sandy, noncalcareous soils on stream terraces.

1. Grayish-brown (10 YR 4/2 dry) friable, massive, sandy loam; in many places breaks into small clods; 6 to 15 inches thick.
2. Light grayish-brown (10 YR 6/2 dry) slightly coherent fine sandy loam or loamy sand; may have some lime spots in lower part; 15 to 30 inches thick.
3. Grayish-brown (10 YR 4/2 dry) loamy sand, or sand and gravel; at depths of 36 inches or more.

The soil is developed on level surfaces, where the drainage is good. The stream terraces are usually used as pasture land, although truck crops, small grains, and forage may be grown on irrigated terrace soils.

SAND HILLS FORMATION

The Sand Hills formation, consisting of well-sorted, pale yellowish-brown (10 YR 6/2), unconsolidated sand, makes up the long northwestward-trending ridges to the north of the Republican River. The Sand Hills formation overlies the Grand Island formation and in some places covers the Pleistocene and Recent sandy silt and clay. Its exact age is unknown, and the maximum estimated thickness is 100 feet.

Extent and distribution.—North of the Republican River, the Sand Hills formation covers a considerable portion of the area. The hills, 25 to 170 feet high, form northwestward-trending longitudinal ridges as much as 10 miles long. They are composed of many small individual ridges and depressions, many of which also trend northwestward. Between the sand hills are broad, flat areas underlain by sandy silt and clay.

Previous work.—The Sand Hills formation, occupying nearly 20,000 square miles of north-central and western Nebraska, and parts of western Kansas and Colorado, was named in 1934 by Lugn (1934, pp. 321, 322, 331, 350). The Sand Hills region of Nebraska is described in three publications of the Nebraska Geological Survey (Lugn, 1934; Condra and Reed, 1943; Condra, Reed, and Gordon, 1947).

Lithology.—The pale yellowish-brown (10 YR 6/2) sand is composed of clean grains, rounded and frosted, mostly quartz and some feldspar fragments. The sand is well sorted, 80 percent of the grains falling between 0.1 millimeter and 0.5 millimeter in size. No bedding was found. The maximum estimated thickness of the Sand Hills formation is 100 feet.

Fossils and age.—No fossils were found in the Sand Hills formation; therefore the exact age of the formation is unknown. Most of the sand hills are covered with coarse grass, indicating that the hills are mature, although at some places where blowouts are forming in the hills, the sand is moving. Lugn (1934, p. 350) suggested that the source of the sand dunes and the Peorian loess was identical, and that they were contemporaneous. Inasmuch as the authors believe that much of the sand in the Wray area was deposited later than the loess, the age assigned to the Sand Hills formation in this paper is late Pleistocene and Recent. The formation is probably in part contemporaneous with the valley fill and the Pleistocene and Recent sandy silt and clay.

Soils.—(Soil description based on unpublished report by the Soil Conservation Service and Colorado Agricultural Experiment Station.) In some places, the surface of the sand hills is stabilized by vegetation, but no true soil is developed. In low spots, and on gently rolling or flat areas within the sand hills, enough organic and fine mineral material has accumulated to darken and stabilize the surface of the sand, thus forming a soil layer 2 to 8 inches thick.

RECENT SERIES

ALLUVIUM

Recent alluvium in the Republican River valley consists largely of reworked valley fill. The Republican River heads in this area, and because it is a very small stream, only a small amount of fine sand and gravel is deposited in the bed. This deposit is too narrow to be mapped on the present scale. The alluvium in the valley of the Arikaree River covers the flood plain with a sheet of sand and gravel which is exposed in the extreme southeast corner of the area.

GEOLOGIC HISTORY

The oldest formation exposed in the Wray area is the Pierre shale, of Late Cretaceous age. Overlying the Pierre shale is the Pliocene stream-laid Ogallala formation, which is composed of silt, sand, and pebbles, irregularly cemented with calcium carbonate. The Pleistocene Grand Island formation, predominantly sand and gravel, overlies the Ogalalla formation. Much of the Grand Island formation was eroded before the next formation (the eolian Peorian loess) was laid down. The Peorian loess is partly contemporaneous with the later deposits, because some of the loess (as it was blown into the area) was reworked by streams and deposited with the Pleistocene and Recent sandy silt and clay and the late Pleistocene and Recent valley fill. Sand from the late Pleistocene and Recent Sand Hills formation was also incorporated into the valley fill and the sandy silt and clay. The youngest unit exposed in the area is the alluvium of Recent age.

The Pierre shale, the oldest formation exposed in the Wray area, is marine in origin. It was laid down in the vast Cretaceous inland sea which covered eastern Colorado and much of the surrounding area when the sea was withdrawing from the Rocky Mountain geosyncline. The formation thins toward the east, from 5,000 feet near Boulder, Colo., to 1,500 feet near the eastern border of the state. The Julesburg Basin was formed during the Laramide uplift, when the Cretaceous and earlier sedimentary rocks were warped and then eroded.

A long period of erosion ensued between Cretaceous and Pliocene times, causing a distinct unconformity between the Cretaceous Pierre shale and the overlying Pliocene Ogallala formation. In the southeastern corner of the Wray no. 4 quadrangle, the top of the Pierre shale is exposed at elevations near 3,600 feet. About 5 miles northwest of these exposures, the top of the Pierre is at an elevation of about 3,500 feet. Whether the high point thus indicated is structural or erosional in origin could not be determined, because the observable dip of the Pierre is very slight.

The Ogallala formation was deposited on the irregular surface of the Pierre shale. (See fig. 3.) The rounding of pebbles, cross-bedding, and channelling indicate its fluviatile origin. The sand and gravel in the formation are composed predominantly of quartz and feldspar derived from older rocks in the Rocky Mountains, and the greater part of the formation was probably deposited in wide, braided streams flowing from the west, and in shallow lakes. The calcium carbonate in the Ogallala formation was probably derived from limestone beds west of the Wray area by streams flowing over limestone and dissolving considerable quantities of lime, which were subsequently precipitated with the sand, silt and gravel of the Ogallala formation. The thickness of the Ogallala formation in the western part of the area is estimated at 220 feet. In the southeastern part of the area, the formation thins and disappears and the Peorian loess rests directly on the Pierre shale. The thinning of the formation is probably due in part to nondeposition over the high point in the underlying Cretaceous Pierre shale; some of the Ogallala formation may have been removed by erosion.

It is probable that the Grand Island formation was deposited on the Ogallala formation by streams flowing toward the east or southeast from the Rocky Mountains during the Kansan stage. The gravel contains rounded pebbles of rocks similar to those exposed in the Rocky Mountains. The pale reddish-brown (10 R 5/4) silt in the gravel may be derived from the Ogallala formation, or it may be wind-blown silt which has been reworked and deposited with the gravel. In the E½ sec. 10, T. 3 N., R. 44 W., a light olive-gray (5 Y 6/1) silty, clayey marl (believed to be identical with the Sappa formation of Yarmouth age) overlies the gravel. This single exposure may be a remnant of a formation that once covered the entire area and which has been removed by erosion.

The eastward-trending valleys of Chief Creek and the Republican River were probably already established at the close of Tertiary time. In late Kansas, Yarmouth, and early Illinoian time (prior to the deposition of the Peorian loess) the valley of the Republican River was enlarged and the steep ravines of tributary streams were cut in the Ogallala formation and in some places down to the Pierre shale, thus removing all but a few very small remnants of the Sappa formation, and leaving some of the Grand Island formation on terraces above the streams. Present drainage probably roughly follows Pleistocene drainage, although at that time many more drainage channels existed north of the Republican River than at present.

Many of the ravines tributary to the valley of the Republican River and the Arikaree River trend northwestward. In areas underlain by flat-lying sediments (as in the Wray area) most tributary streams flow at an angle to main streams, and the acute angle between the main stream and the tributary is located upstream from their juncture. Many of the northwestward-heading tributary streams in the Wray area form an obtuse angle with the main stream throughout most of their length, and bend to form the usual acute angle only in their lower portion, near the point where they join the main stream. This type of drainage is well illustrated in the southeast corner of the accompanying geologic map. The northwestward trend of the drainage in the Wray area is typical of much of the drainage in the Great Plains.

Several hypotheses have been advanced to explain the northwest trend of tributary drainage in the Great Plains. W. L. Russell (1929) considered and discarded several factors which might influence the trend of drainage, including structural control and tilting of the surface. He suggested that the wind was probably the dominant (although indirect) factor in establishing aligned drainage south of the North Platte in South Dakota, where the streams flow between northwestward-trending eolian sand hills. He further suggested that aligned drainage over much of the Great Plains may have been established between northwestward-trending dunes formed in sandy Tertiary formations which were subsequently removed by erosion. C. L. Baker (1948, pp. 5–8), working in western South Dakota, postulated that drainage was established in elongate northwestward-trending deflation basins in the Pierre shale. The deflation basins became filled with water and overflowed into adjacent basins; the streams thus established grew headward along the length of the deflation basins.

D. R. Crandall,[1] working in South Dakota, stated that the longitudinal sand dune hypothesis of drainage orientation does not satis-

[1] Crandall, D. R., 1951. Geology of parts of Hughes and Stanley Counties, South Dakota: Doctorate thesis, Yale University.

factorily explain drainage alignment in broad areas of the Great Plains where no sand dunes are now present and where no indications of previous sand deposits have been found. He further stated that the northwestward-trending drainage was probably established in late Kansas time, and that present drainage is continuing along northwestward-trending deflation basins.

In the Wray area, the drainage was established prior to Peorian time; this is proven by the fact that many of the ravines are completely filled with Peorian loess. Therefore, drainage must have been established prior to deposition of the Sand Hills formation, which is younger than the Peorian loess. Consequently, the northwestward-trending sand hills north of the Republican River and the northwestward-trending depressions and ridges in the Peorian loess south of the river had no effect on establishing the trend of pre-Peorian drainage.

Northwestward-trending sand hills or deflation basins may have been formed in the loose sands and silts of the Grand Island and Sappa formations during the Yarmouth interglacial stage, before these formations were removed by erosion. Northwestward-trending drainage established at that time would have become entrenched in the underlying Ogallala and Pierre formations and would continue to trend northwestward until the present time.

The wind may also have had a direct as well as an indirect effect in establishing drainage patterns, particularly on the north side of the Republican River, where the northwest trend of the drainage is more pronounced than on the south side. When a strong wind blows water down a slight slope, the water flows in rivulets down the slope, away from the wind; once rainwater blowing down a slope in this manner starts to erode the surface and form gullies, the heads of the gullies will advance upstream (and upslope) against the wind and will continue to erode in this direction. During Pleistocene time, rainwater may have been blown by a northwest wind down the slight slope toward the Republican River or the Arikaree River, on the north or northwest side of the stream, thus forming gullies which head northwest, although the normal headward direction, if uninfluenced by the wind, may have been west or southwest.

During Peorian time, the wind was the dominant depositional agent and deposited loess over much of the area. It is probable that the source of the Peorian loess was the flood plains of rivers north and northwest of the Wray area. In glacial stages before Peorian time, large quantities of sand and silt, carried by streams from Rocky Mountain outwash plains and from Tertiary sandy and silty formations in the region (such as the White River, Arikaree, and Ogallala formations) were deposited on the broad flood plains of the Platte and other rivers north and northwest of the Wray area. During Peorian time, the wind blowing from the northwest picked up silt from these flood plains and from the soft Tertiary formations and dropped it later, thus forming deposits of loess. At the same time, loose sand was blown from the same formations and formed dunes which moved toward the southeast. In the Wray area, in valleys north of the Republican River, and in many of the ravines south of the river, the loess was reworked or carried away by streams, although thick deposits remained on the southern uplands and along the valley sides. In stream valleys north of the Republican River, much of the Peorian loess was reworked and incorporated in the Pleistocene sandy silt and clay. When the valleys became filled, the sandy silt and clay spread over the Grand Island formation on the older terraces. A great amount of sand from the Sand Hills formation was deposited with the silt and clay in late Pleistocene and Recent time.

The valley fill (which covers the flood plain of the Republican River and fills ravines of streams tributary to the valley of the Republican River) consists largely of reworked material from the Ogallala formation and some loess. At no place in the area was the valley fill seen underlying the Peorian loess, and where the fill and loess are in contact at the valley sides they grade into one another. It is probable that the valley fill is younger than, or contemporaneous with, the Peorian loess. The valley fill and the dark surface silts (which overlie the Pleistocene gravels and calcareous sandy clays in many places) grade laterally into each other and are probably partly contemporaneous.

Many of the ravines south of the Republican River were completely choked with valley fill, and subsequent streams (probably during late Wisconsin and Recent time) cut terraces in the fill. In some places, these streams cut through the fill and exposed the bottom and sides of the old valleys in the Ogallala formation, thus leaving terraces of valley fill on the sides of the ravines (see fig. 9).

During late Pleistocene and Recent time, sand dunes advanced into the area north of the Republican River. Lugn (1935) suggested that much of the sand in the sand hills of Nebraska and northeastern Colorado was derived from the Ogallala formation; however, it seems unlikely that this occurred in the Wray area. Although the Ogallala formation is very sandy and includes some slightly unconsolidated beds, most of the sand in this area is cemented by a large amount of calcium carbonate. At no place in the area was a blowout found to be developing in the Ogallala beds, but in the SE¼NW¼ sec. 3, T. 1 N., R. 44 W., along Chief Creek, typical sand dune topography is developed on a sand pocket in the valley fill. This sand is now being cut by Chief Creek and eroded by the wind. It seems probable that at least

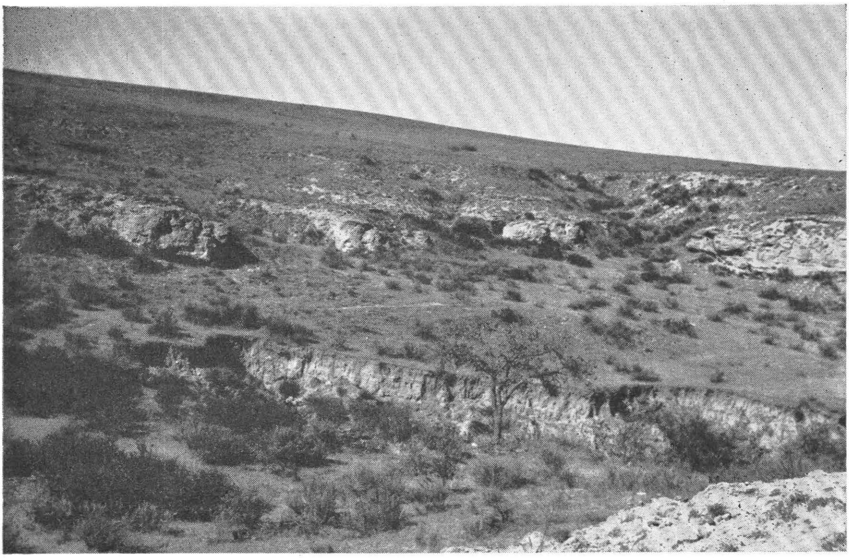

FIGURE 9.—Exposure of valley fill in the NE¼ SW¼ sec. 12. T. 1 N., R. 43 W. Outcrops of Ogallala formation on sides of ravine show that this ravine was eroded in the Ogallala formation and then choked with valley fill. The fill is now being eroded by a headward-cutting gully.

part of the sand of the Sand Hills formation is derived from similar Pleistocene stream sediments.

Sand dunes of the type found in the Wray area usually form with their long axis parallel to the direction of the prevailing wind (Bagnold, 1941, pp. 167–207, 222–235). If the trend of the dunes in the Wray area represents the prevailing wind direction during Pleistocene time, the direction was from the northwest or southeast, and the source of the sand must have been from one of these directions. Therefore, the most probable sources of the sand comprising the dunes are the stream valleys to the north and northwest, and the fine, sandy sediments of the White River and Arikaree formations to the northwest. Northwest of the Wray area, large blowout areas may be seen where wind action has developed badland topography in the soft beds of the White River.

The sand and loess probably have the same source, but during Peorian time the loess, being lighter, was blown farther south than the sand; in late Pleistocene and Recent time the sand migrated southward until it covered the Ogallala formation and most of the area north of the Republican River. As the small streams which still flowed north of the Republican River reworked part of the sand, the dunes piled up between the flat areas of the stream beds. Logs of wells (105 and 111)—drilled in the Sand Hills formation—indicate that some of the ridges have rock cores (probably part of the Ogallala formation). The dune sand has filled the formerly broad valley of the Republican River until it is completely choked with dunes, except for the small flood plain of the present Republican River, which lies between the cliffs formed by the Ogallala formation to the south and the dunes which encroach from the northwest.

ENGINEERING GEOLOGY

The discussion of the engineering geology of the Wray area is divided into two parts: engineering problems, and sources of construction materials. A brief description of the map units is included in the engineering geology, but more complete information regarding the distribution and physical characteristics of the rocks in each map unit may be found in the section on descriptive geology and on the accompanying geologic map (pl. 1).

The following statements in regard to the engineering properties (drainage and permeability, workability, stability, and economic considerations) of the map units are based in part on actual laboratory tests of representative samples made by the Colorado State Highway materials laboratory, Colorado Agricultural College road materials laboratory, Public Roads materials testing laboratory, or by the U. S. Geological Survey. In much greater part, however, they are based on field observations of the behavior of the various map units in road cuts, bridge abutments and the like, in various parts of the quadrangle and in areas nearby. To these field observations have been added information on actual service records as supplied by several local engineers. It is hoped that these generalized statements in regard to engineering properties of the various map units will be of use to engineers and others in laying out preliminary plans and designs. It is obvious that they cannot and should not take the place of detailed investigations (both field and laboratory) that are required in design of specific engineering structures.

ENGINEERING PROBLEMS

The engineering problems to be considered include foundation conditions, drainage, stability in cuts, and ease of excavation. In the following text the problems are discussed for each map unit in the Wray area; these data are summarized in table 2.

FOUNDATION CONDITIONS

Pierre shale.—The Pierre shale crops out along the eastern part of the North Fork of the Republican River and its tributary streams, and in northwestward-heading ravines of streams tributary to the Arikaree River. The shale becomes very soft and slippery when wet, and the weathered near-surface zone, from one-half foot to 25 feet deep, is particularly unstable. If possible, foundations of roads or

TABLE 2.—*Properties and uses of earth materials in the Wray area*

[*A* indicates good, *B* fair or adequate, *C* poor or unsuitable]

Geologic unit	Foundation conditions	Drainage	Stability in cuts	Removal (equipment required)	Surfacing	Ballast	Base course	Binder	Mineral filler	Blending sand	Pozzolan	Concrete aggregate	Fill
Sand Hills formation.	*A* if confined, *B–C* if unconfined.	*A*	*C*	Hand tools	*C*	*C*	*C*	*C*	*C*	*B*	*C*	*C*	*A–B*.
Valley fill	*B*	*A* if water table low, *C* if water table high.	*A–C*	Hand tools to power tools.	Gravel *A*	Gravel *B*	Gravel *B*	Sandy silt *B*	*C*	Gravel *B*, sand *B*.	*C*	*C*	Gravel *B*, sand *A–B*.
Sandy silt and clay.	*B*	*A* if much sand, *C* if much clay.	*A* if little sand, *C* if much sand.	Hand tools to power tools.	*C*	*C*	*C*	*B*	*C*	*C*	*C*	*C*	*B*.
Peorian loess	*B–C*	*C*	*A–C*	Hand tools	*C*	*C*	*C*	*C*	*A*	*C*	*C*	As ceramic slag *B*.	For earth dams *B*.
Grand Island formation.	*A*	*B–C*	*A* if little sand, *C* if much sand.	Hand tools to power tools.	*B*	*B*	*B*	*C*	*C*	*B*	*C*	*B*	*B*.
Ogallala formation.	*A–B*	*A*	*A–C*	Hand tools to blasting.	Gravel *B*	*B*	*B*	*C*	Ash *A*	Gravel *B*.	Ash *B*.	Gravel *B*.	Gravel *B*.
Pierre shale	*B*	*C*	*C*	Hand tools	*C*	*C*	*C*	*C*	*C*	*C*	May be suitable if calcined; not tested; see text.		*C*.

other structures should be constructed on firm, unweathered rock. Roads constructed on the Pierre shale should be well drained and surfaced.

Ogallala formation.—Few foundation problems are encountered when building on the Ogallala formation, which underlies the unconsolidated surface deposits in most places and is exposed as bluffs along the south side of the Republican River. Most of the rock consists of sand cemented with varying amounts of calcium carbonate, and the unconsolidated beds alternate with well-cemented beds at short intervals to provide a firm footing. Cementation is so irregular that no bedding plane is extensive enough to become a slippage plane and cause landslides.

Grand Island formation and sandy silt and clay.—The Pleistocene and Recent sandy silt and clay is exposed in flats between the sand hills north of the Republican River and is underlain in some places by the Grand Island formation. The fine, reddish-brown (10 R 5/4) gravel of the Grand Island formation is a fairly stable foundation material. The silt and clay content of the pale yellowish-brown (10 YR 6/2) sandy silt and clay varies from place to place. The sandy silt and clay forms a suitable foundation for small buildings, except in small scattered areas where the clay content is high. In these areas the material may compact when saturated.

Unsurfaced roads built on this map unit vary from those built on loose non-cohesive sand and silt, which are trafficable when wet but offer poor traction when dry, to roads built on clay, which become impassable in wet weather.

The distribution of the Grand Island formation is unknown because it is everywhere covered by the sandy silt and clay, and is exposed only in man-made pits; therefore, the Grand Island formation and sandy silt and clay have been treated as a single unit in this report.

Peorian loess.—Deposits of Peorian loess as much as 130 feet thick mantle the rolling uplands south of the Republican River. It consists of yellowish-gray (5 Y 7/2) calcareous silt, and is classified by Casagrande (1948) as an ML soil, and by the Public Roads Administration as a class A–4 soil (Bollen, 1945, p. 291). The loess presents special foundation problems for large structures because it tends to consolidate under load when wet. However, it is a fair foundation material for small buildings and is a fair to poor subgrade material for roads. Loess is easily eroded, and roads built near the heads of large ravines in loess will be quickly damaged by headward erosion. Roads constructed on loess in this area develop small gullies which cut into the shoulders during the rainy season and make constant filling and maintenance necessary in order to prevent dangerous erosion into the roadbed. Small landslides called "cat-steps" are frequent in the loess (Gwynne, 1950), which is unstable and flows easily under load when saturated.

Laboratory tests made on loess by Holland and King (1949), of the U. S. Bureau of Reclamation, show that loess is very weak when wetted, although it has relatively high compressive strength under certain conditions of loading and low moisture content. Permeability was found to be greater vertically than horizontally because of the large number of small, vertical root holes in the loess, which conduct the water. They state:

> * * * loess is composed primarily of silt and sand grains coated with clay and sparse calcite which have been deposited in such a manner that the resulting texture is a loose, open, framework with only point-to-point contact between the grains. This material, therefore, is susceptible to consolidation under load. Clay and to a lesser extent calcite, act as binding materials which give the loess a relatively high compressive strength, but as soon as the strength of the clay and calcite binder has been exceeded by loading, consolidation takes place rapidly until the particles have rearranged themselves into a more dense structure capable of sustaining the load. When the dry loess is wetted, the clay softens, cohesion decreases, and only a comparatively small load is necessary to collapse the internal structure, with resulting consolidation and differential settlement of the loess.

Valley fill.—The valley fill, which forms flood plains and terraces of the Republican River and its tributary streams, is very irregular in composition. In some places it consists largely of loesslike silt, and in other places it is composed of sand and gravel. However, the major part of the valley fill is a sandy silt which forms a fair foundation for roads and small buildings. In areas where the fill is loesslike, the same foundation conditions exist as in loess; where it is very sandy, the same foundation conditions exist as in dune sand of the Sand Hills formation.

Sand Hills formation.—The sand of the Sand Hills formation, which forms long, northwestward-trending ridges north of the Republican River, is a Casagrande (1948) SP construction material. If confined, the sand is a good foundation material; if unconfined, it is a fair foundation for small buildings, but a poor material for roads. Unimproved sand roads are satisfactory in wet weather, when the sand is firm and compact, but they become impassable in dry weather, when the sand is soft and loose. Roads through the sand hills cannot be maintained by grading; they must be surfaced in some manner, and even then the road surface is not easily maintained, because the sand drifts over the road from cuts. Most of the gravel available from other formations in the area is suitable for surfacing roads in the sand hills because it contains silt and clay which act as a binder to stabilize the sandy soil.

DRAINAGE

Pierre shale.—The Pierre shale drains very poorly, and the shale becomes a plastic impervious clay when saturated. Roads constructed on Pierre shale should have a suitable, well-drained subgrade.

Ogallala formation.—The Ogallala formation is porous and permeable.

Grand Island formation and sandy silt and clay.—The gravel of the Grand Island formation is well-drained in locations above the water table. The sandy silt and clay is permeable in most places because it contains a large amount of sand. If roads are built over marshy places and undrained depressions where the percentage of clay in the sandy silt and clay is high, adequate drainage should be provided.

Peorian loess.—Because reworked loess drains very poorly, low places in unsurfaced roads constructed on loess accumulate rainwater, and puddles which form on the roads do not dry up for several months. A roadbed constructed of loess will absorb a large amount of water; freezing causes the loess to heave in the winter and results in a rough and dangerous riding surface. In the spring, thawing of the ice makes the loess almost fluid; such a condition may result in failure of road surfaces, and it could make unsurfaced roads almost impassable in the spring rainy season.

Valley fill.—Most of the valley fill contains sand; therefore, it is well drained except in places where the water table is very close to the surface.

Sand Hills formation.—The sand hills are porous and permeable.

STABILITY IN CUTS

Pierre shale.—The slope angle of eroded cutbanks and gully walls in Pierre shale seldom exceeds 45°. Cuts made steeper than this angle have a tendency to slump.

Ogallala formation.—The mortar beds of the Ogallala formation will stand in vertical cuts, but the poorly consolidated beds between them have a natural angle of repose ranging from about 30° to almost vertical. The amount of slump, and the angle to which they should be cut, vary with the amount of cementation of each bed. In a railroad cut in sec. 21, T. 2 N., R. 44 W., pole matting has been used to retain these unconsolidated beds.

Grand Island formation and sandy silt and clay.—The Grand Island formation and the Pleistocene and Recent sandy silt and clay will stand in almost vertical cuts, except where the percentage of sand in the sandy silt is high. In these places, sand drifting across the roadbed from the cuts is to be expected.

Peorian loess.—Construction experience indicates that cuts in loess should be steep. Backslopes of deep cuts for a canal through silty loess in south-central Nebraska were designed to be ¼ (horizontal): 1 (vertical) for slopes whose maximum height did not exceed 55 feet. For higher slopes, or sandier loess, backslope angles of ½: 1, ¾: 1, and 1½:1 were adopted (Turnbull, 1948). If cuts are constructed with steep slopes, they will stand for a long period of time without much slumping, because the natural slope angle of loess is very steep. On gentler slopes, however, rainwash and erosion may be severe. In 1940 the Iowa State Highway Commission used a terrace design for deep (80 feet) highway cuts in loess; the design is considered reasonably successful (Gwynne, 1950).

Valley fill.—The composition of the valley fill varies widely, and the angle of repose varies accordingly. The angle of slope in cuts should approximate the natural angle of repose. Where the valley fill is silty and loesslike, it will stand in vertical cuts, but where the percentage of sand increases, the angle of slope decreases, until in sand pockets the angle of repose is about 30°.

Sand Hills formation.—Road cuts in sand hills are very unstable because they slump to the natural angle of repose of loose, dry sand (approximately 30°). Road cuts in the sand hills are easily eroded by wind, and large amounts of sand drift onto the roadway from the cuts. Stabilization of banks and cuts in sandy areas is aided by seeding and pole matting.

EXCAVATION

Pierre shale.—When dry, the Pierre shale may be easily excavated with hand or power tools. However, water-saturated Pierre shale becomes a sticky, plastic clay which will stick to tools and be extremely heavy and difficult to move.

Ogallala formation.—All beds of the Ogallala formation may be easily excavated with power tools, except for a few very well cemented beds. Even these beds can be removed without blasting, although the work may be somewhat laborious. The extremely hard beds are very thin and may be broken with a power shovel and removed in blocks.

Grand Island formation and sandy silt and clay.—The Grand Island formation and the sandy silt and clay may be dug with hand or power tools. The fairly well consolidated gravel is difficult to dislodge with a spade, but when struck sharply with a pick, the cement crumbles, and the loose gravel can then be scooped up with a shovel.

Peorian loess.—The loess is easily excavated with hand or power tools.

Valley fill.—The valley fill may be easily dug with hand or power tools.

Sand Hills formation.—The sand is loose and unconsolidated; it is easily moved with hand or power tools.

SOURCES OF CONSTRUCTION MATERIALS

Possible usage of construction materials found in the Wray area during the course of the field investigation was classified in accordance with the results of laboratory tests. Not all map units are listed under each construction material considered in the text; only those rocks are discussed which are recommended for use. The rocks of all map units, whether suitable or unsuitable for construction, are rated in table 2. The tests and the agency doing the work are noted in table 3, which immediately precedes this page. Size analyses of all materials are shown on the graph given in figure 10. The size analyses and the general characteristics shown in table 3 and figure 10 for the gravel of the Grand Island formation, the gravel of the Ogallala formation, the ash, the loess, and the dune sand, show that material from each of these map units varied only slightly from place to place. The Pleistocene sandy silt and the sand and gravel from the valley fill are variable, and analyses are different for each exposure.

Good construction materials are scarce. The deposits of gravel of the Grand Island and Ogallala formations are small and irregular, loosely cemented with clay, silt, and calcium carbonate, and contain very few pebbles larger than one-half inch in diameter. The gravel is unsuitable for concrete aggregate, but it may be used for ballast, base- and top-course. Existing pits are small, and new deposits are difficult to find. The large and readily available deposits of pure ash in the Ogallala may be used as mineral filler, pozzolanic material, and cleansing powders. Large amounts of the sandy silt and clay may be used for binder. The almost unlimited deposits of Peorian loess are a possible source of ceramic slag aggregate and mineral filler. Large amounts of blending sand and earth-fill dam material are available in the valley fill.

No deposits of rock for crushed rock aggregate, riprap, or building stone were found. Small lenses of limestone in the Ogallala formation may be suitable for these uses, but the thick overburden and small deposits make them commercially unexploitable. The available construction materials in the Wray area are described according to use and geologic unit.

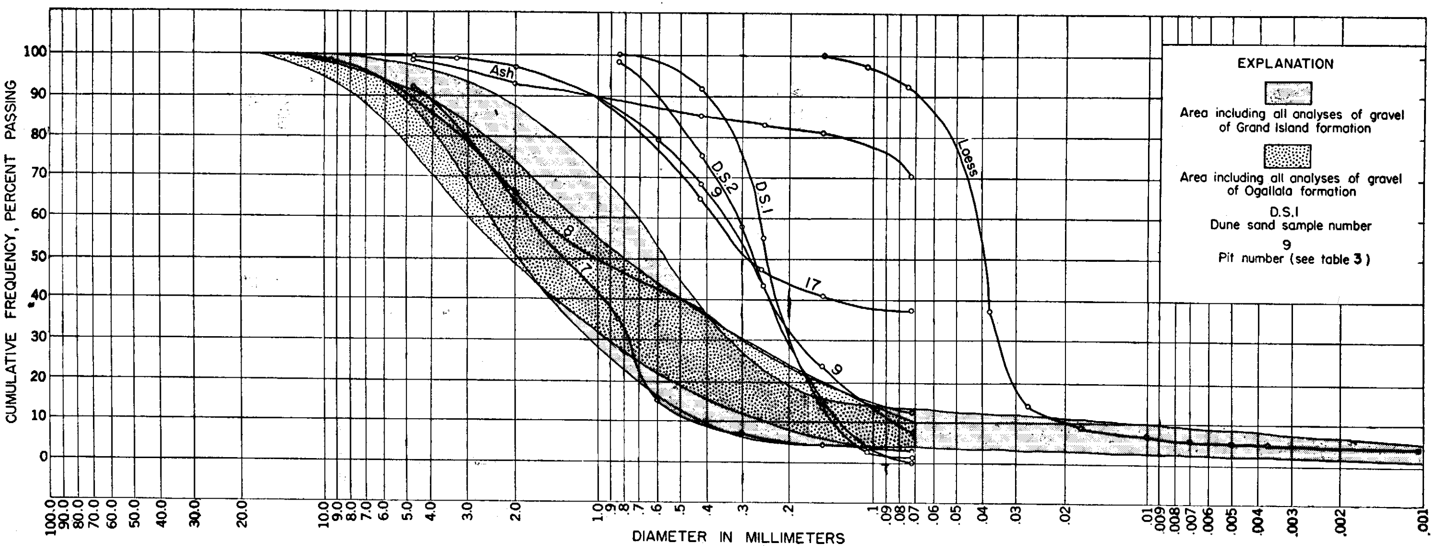

FIGURE 10.—Size analysis graph of construction materials in the Wray area.

SURFACING

Ogallala formation.—Gravel suitable for surfacing is found in the basal conglomerate of the Ogallala formation which crops out along the south side of the Republican River in the eastern half of the area. It is reported that it has been used in the Wray area for surfacing with good results. Some of the gravel, because of an excessive amount passing through the no. 10 screen, is not considered suitable for surfacing. The gravel is classified as fine (75 percent falling between 5.0 millimeters and 0.1 millimeter in size); it contains subangular to round pebbles of quartz, feldspar, granite, diorite, basalt, quartzite, and limestone. Quartz and feldspar predominate, and most of the feldspar is slightly weathered and moderately sound. Most of the gravel contains silt, sand, and calcium carbonate, as well as minor amounts of limonite and clay balls. The silt and clay particles may be removed by washing. The gravel is 2 to 10 feet thick and is overlain by 2 to 10 feet of unconsolidated to semiconsolidated sand and silt overburden. Calcium carbonate-cemented aggregates in the gravel will break down under load; this weakness of cementation prevents use of crushed Ogallala for aggregate. The location and extent of existing pits is shown in table 3.

Grand Island formation.—Only a small amount of the gravel of the Grand Island formation is suitable for surfacing because too high a percentage passes through the no. 200 screen to be acceptable. It has been used successfully on sandy roads, where the fine fraction, composed of silt and calcium carbonate, acts as a binder for the sand. The gravel is fine, 85 percent falling between 5 millimeters and 0.2 millimeter in size and containing much calcium carbonate, clay, and silt. The gravel consists largely of particles of quartz and feldspar, which are sound to moderately sound. The gravel is exposed only in man-made pits in the northwestern part of the Wray area; the location of the pits is shown on the accompanying geologic map and on table 3. The gravel is 2 to 15 feet thick and is overlain by 1 to 8 feet of overburden, some of which is hard, calcareous, sandy silt and clay.

Valley fill.—Gravel from small pockets containing as much as 15,000 cubic yards in the valley fill has given good results as surfacing. Sand and gravel from the valley fill is free of silt, clay, and organic material. The gravel contains some large pebbles, but 55 percent of the material is between 5.0 millimeters and 0.5 millimeter in size. The gravel is about 8 feet thick and is overlain by 2 to 4 feet of sandy silt overburden.

BALLAST

Ogallala formation.—The gravel from the Ogallala formation is suitable for use as ballast.

Grand Island formation.—The gravel of the Grand Island formation is suitable for use as ballast. Some of the gravel has reportedly been used for this purpose, but no performance record is available.

Valley fill.—Gravel from the valley fill may be used as ballast.

BASE COURSE

Ogallala formation.—Some of the gravel from the basal part of the Ogallala formation is recommended for use as base course. (See table 3.)

Grand Island formation.—The gravel of the Grand Island formation is recommended for use as base course.

Valley fill.—Gravel from the valley fill is suitable for use as base course.

BINDER

Sandy silt and clay.—The Pleistocene and Recent sandy silt and clay is suitable for use as base course binder. Only one pit was found (see table 3), but this kind of material is widespread, and the supply is large. Material suitable for binder may be found in much of the area shown on the map as "sandy silt and clay." Material from the pit located on the map has given fair results when used as binder for sandy roads. The calcareous sandy silt and clay is overlain by 1 to 3 feet of dark yellowish-brown sandy silt.

Valley fill.—Sandy silt and clay from the valley fill is suitable for use as binder.

MINERAL FILLER

Ogallala formation.—Volcanic ash in the Ogallala formation crops out a few miles west of the town of Wray and is recommended for use as mineral filler. The ash is pure, white, and uniform in particle size. The bed of ash is about 10 feet thick; overburden may be as much as 50 feet of unconsolidated to semiconsolidated Ogallala beds, although a large amount of ash is available with little or no overburden.

Peorian loess.—Loess has been used extensively in Kansas and Nebraska as mineral filler, with good results. The supply of loess near Wray is practically unlimited (seen by outlining the large area of loess shown on the map). The loess has very little overburden except sod.

BLENDING SAND

Ogallala formation.—If the gravels of the Ogallala formation are washed to remove the silt and calcium carbonate, they may be blended with coarse gravels for use as concrete aggregate and surfacing.

Grand Island formation.—The silt, clay, and calcium carbonate may be removed from the gravel of the Grand Island formation by washing. This washed gravel is suitable for blending with coarse gravel for use as concrete aggregate and surfacing.

Valley fill.—One large deposit containing more than 50,000 cubic yards of sand (apparently suitable for use as blending sand for mortar, surfacing, and concrete aggregate) was found in the valley fill. This prospect is shown as pit no. 9 on table no. 3. No performance record for this sand is available. The sand is clean, moderately well-sorted, and overlain by 6 inches of soil and vegetation.

Sand Hills formation.—The sand from the Sand Hills formation is suitable for use as blending sand for mortar, surfacing, and concrete aggregate. An abundant supply is available north of the Republican River. The sand consists largely of rounded grains of quartz and feldspar and is free from organic material, silt, clay, and other fine materials. It is unconsolidated and is moderately well sorted; 80 percent of the sand particles fall between 0.01 millimeter and 0.05 millimeter in size.

POZZOLAN

Pierre shale.—Shales similar to the Pierre have been used, after calcination, as pozzolans; if a source of pozzolan is sought in the Wray area, the Pierre shale should be considered and tested.

Ogallala formation.—The volcanic ash in the Ogallala formation may be suitable for use as a pozzolanic material. Pumicite from the Ogallala formation near Ellis, Kan., which was tested for pozzolanic quality by the Bureau of Reclamation (Mielenz, Greene, and Schieltz, 1951), was found to reduce mortar expansion and increase mortar strength. The ash in the Wray area contains about 95 percent glass, which is slightly altered, and has an index of refraction of 1.497. Although many satisfactory pozzolans owe their activity primarily to rhyolite glass with a refractive index in the range of 1.490 to 1.507, not all volcanic glasses of this refractive index are satisfactory pozzolans. Suitability of rhyolite glass for pozzolan cannot be predicted by petrographic or chemical analyses and must be tested by empirical methods.

No tests have been made to determine whether the volcanic ash of the Ogallala formation in the Wray area would counteract the reaction of deleterious aggregate with high-alkali cement. Mielenz and others (1949), and Mielenz, Witte, and Glantz (1950), of the Bureau of Reclamation, state that only a few pozzolans will satisfactorily control alkali-aggregate reactions. Most volcanic tuffs and ashes, fly ash, siliceous sedimentary rocks and calcined clays and shales may be used as pozzolans to increase the resistance of concrete to attack by sulfate-carrying waters, reduce heat generation in massive structures, save portland cement, increase tensile strength of concrete, reduce permeability of concrete, and improve workability of the concrete mix. However, only the following pozzolans are known to control the alkali-aggregate reaction in concrete and mortar: (1) Aluminous and siliceous amorphous materials, such as some opals, certain rhyolitic volcanic glass, diatomaceous earth, calcined kaolinite, and some artificial siliceous glasses; (2) many opals and opaline cherts showing a partial X-ray powder diffraction pattern of beta-cristobalite; and (3) calcined montmorillonite-type clays usually inseparably admixed with cristobalite.

CONCRETE AGGREGATE

Pierre shale.—The clays of the Pierre shale may be a source of ceramic slag aggregate. No tests were made to determine suitability.

Ogallala formation.—The gravel from the Ogallala formation has been used as concrete aggregate, but no performance record is available. It is not recommended for this purpose because of its fine particle size and high percentage of silt and calcium carbonate. If it is washed to remove the fines, the gravel may be used in concrete aggregate after it is blended with coarser material.

Grand Island formation.—Gravel from the Grand Island formation is not recommended for use as concrete aggregate because of its fine particle size and high percentage of clay, silt, and calcium carbonate. If the fines are removed by washing, the gravel may be blended with coarse material for use in concrete aggregate.

Peorian loess.—Ceramic slag suitable for use as concrete aggregate has been made from Pleistocene silt in western Kansas by Plummer and Hladik (1948) of the Kansas Geological Survey. Because gravels in the Wray quadrangles are very poor construction materials, and Pleistocene loess (similar to loess in western Kansas) is abundant, ceramic slag made from the loess may provide constructional aggregate for the Wray area which would be more satisfactory than the natural materials of the region.

Tests made by Plummer and Hladik indicate that the slag is suitable for railroad ballast, concrete aggregate, and allied uses. The estimated cost of producing it ($1.10 to $1.70 per cubic yard, large scale production in a rotary kiln) compares favorably with the cost of natural materials used for these purposes in the same area. Green and Schieltz (1948) of the Bureau of Reclamation petrographic laboratory in Denver, have analyzed these slags and have found them to be composed largely of quartz and glass, with minor amounts of plagioclase feldspar, mullite, and diopside. The glass content ranges from 20 to 50 percent and has a relatively high silica content. The slag is vesicular, although the size of the pores varies greatly. Tests made by the Bureau of Reclamation indicate that because of its high glass content the slag would be deleteriously reactive if used as concrete aggregate with high-alkali cement, although possibly the porosity of the slags would reduce the destructive effect of the reactivity by providing space in which the reaction product could be accommodated. No empirical tests have been made to determine whether or not this is true.

FILL

Ogallala formation.—Some of the sand and gravel from the Ogallala formation is suitable for artificial fill. Although crushed mortar beds may be used as fill, the mortar beds are not recommended for this use because the loosely cemented rock will gradually disintegrate and compact under load when wet.

Sandy silt and clay.—The Pleistocene and Recent sandy silt and clay contains material suitable for impervious and semipervious zones of earth fill dams. The sandy silt is also a fair material for fill in low places and swampy areas. However, the material should be tested before using, because the percentage of sand in the sandy silt and clay varies from place to place. Materials high in silt and clay are unsuited for fill.

Peorian loess.—Loess is suitable for use in the semipervious layers of earth dams. It is extremely poor fill material for low or swampy areas, as it flows easily under load when wet.

Valley fill.—The silty portion of the valley fill has been selected by Osborn, Dermeyer, and Nesbitt (1947), engineers of the Bureau of Reclamation, as suitable impervious material for earth-fill dam construction. This material may also be used for other types of fill.

Sand Hills formation.—The sand from the Sand Hills formation is a fair material for use in the semipervious zone of earth dams. It is also a good fill material for low or swampy areas and other types of artificial fill.

WELL LOGS

With the exception of geologic interpretation, the logs of wells included in this appendix are exactly as they were given to the authors by the source which is shown as "Authority" at the top of each log. Logs received from the Bureau of Reclamation were partially interpreted when obtained; formations or map units mentioned in other logs were added by the authors. Altitudes for most of the logs are unknown. Terms used in the logs are those obtained from the original source (usually the driller) and they have not been edited. Such names as "seep water gravel" and "magnesia" are driller's terms, and their exact meaning is not always clear. Logs which list the Ground Water Branch, Geological Survey, as the authority, are also drillers' logs; they were copied from drillers' records by the Ground Water Branch, which made them available to the authors. The names of the drillers who gave these logs to the Ground Water Branch are unknown.

Well 100a, NE¼ sec. 8, T. 1 N., R. 44 W. Altitude 3,650.7 feet

[Authority, Bureau of Reclamation]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Dune sand, fine, loose, damp, brown	45.0	45.0
Valley fill:		
Sand, medium, compact, saturated, brown	12.0	57.0
Ogallala formation:		
Ogallala clay, clean, plastic, saturated, brown	15.0	72.0
Ogallala sand, medium, compact, saturated, clean	10.0	82.0
Pierre shale:		
Pierre shale, soft, rust-coated fractures, saturated, brown	7.0	89.0
Pierre shale, firm, saturated, black	3.5	92.5

Well 100b, NE¼ sec. 8, T. 1 N., R. 44 W. Altitude 3,623.7 feet

[Authority, Bureau of Reclamation]

	Thickness (feet)	Depth (feet)
Valley fill:		
Silty fine sand, soft, moist, brown	15	15
Silty fine sand, compact, saturated, brown	17	32
Medium sand, compact, saturated, clean	14	46
Medium sand, compact, saturated, brown (cross-bedded)	7	53
Pierre shale:		
Pierre shale-clay (weathered), plastic, saturated, gray	6	59
Pierre shale (a few rust seams), firm, saturated, black	8	67

Well 100c, NE¼ sec. 8, T. 1 N., R. 44 W. Altitude 3,611.4 feet

[Authority, Bureau of Reclamation]

	Thickness (feet)	Depth (feet)
Valley fill:		
Loam, sandy, soft, moist, dark-brown	5	5
Clay, sandy, soft, wet, gray	4	9
Sand, fine, compact, saturated, gray	12	21
Sand, medium, compact, saturated, brown	15	36
Sand, fine, compact, saturated, brown	2	38
Sand, medium, compact, saturated, brown	6	44
Pierre shale:		
Pierre shale (some silty layers), firm, saturated, black	4	48

Well 100d, NE¼ SE¼ sec. 8, T. 1 N., R. 44 W. Altitude 3,617.5 feet

[Authority, Bureau of Reclamation]

	Thickness (feet)	Depth (feet)
Valley fill:		
Fine sand, soft, moist, dark-brown	3	3
Silty fine sand, soft, moist, brown	7	10
Silty fine sand, compact, saturated, gray	10	20
Medium sand, compact, saturated, clean	25	45
Pierre shale:		
Pierre shale clay (weathered), soft, brown	2	47
Pierre shale, soft, saturated, black	6	53

Well 100e, SW¼ sec. 9, T. 1 N., R. 44 W. Altitude 3,676.5 feet

[Authority, Bureau of Reclamation]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Loam, silty, compact, moist, brown	1	1
Ogallala silt, sandy, dry, buff	6	7
Ogallala fine sand, silty, some lime cementation, firm, dry, gray	12	19
Ogallala fine sand, partially lime cemented, firm, moist, gray	11	30
Ogallala clay, silty to sand, some lime cementation, firm, saturated, brown	28	58
Ogallala fine sand, compact, saturated, some concretions, brown	5	63
Ogallala medium sand, compact, saturated, brown	13	76
Pierre shale:		
Pierre shale (with black shale, weathered), plastic, saturated, green and limonite layers	30	106
Pierre shale, firm, saturated, black	4	110

Well 101, SW¼SE¼ sec. 23, T. 3 N., R. 46 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sandy silt and clay:		
Soil	4	4
Sandy loam	20	24
Clay strips	8	32
Ogallala formation:		
Gravel and sandy clay	28	60
Seep water gravel	73	133

Well 102, Middle of N line of NW¼ sec 26, T. 3 N., R 46 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Soil	2	2
Sand	48	50
Ogallala formation:		
"Magnesia"	20	70
Gravel, seep water	10	80
Clay	20	100
Gravel	42	142
Bottomed in hard rock	----------	----------

Well 103, NW¼ sec. 26, T. 2 N., R. 46 W.

[Authority, City of Eckley (city well)]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Sand	32	32
Ogallala formation:		
Sand rock	10	42
Lime rock	5	47
Lime rock and gravel	8	55
Clay	3	58
Porous rock	15	73
Sand rock	16	89
Clay	35	124
Lime rock	38	162
Sand rock	36	198
Gravel	47	245
Pierre shale:		
Clay	12	257
Soapstone	11	268
Shale	32	300
Blue shale	15	315

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Well 104, Center NW¼ sec. 21, T. 3 N., R. 45 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
White sand	3	3
Sandy silt and clay:		
"Gumbo"	8	11
Grand Island formation:		
Sand	6	17
Gravel	10	27
Ogallala formation:		
Sand	10	37
Gravel (14 feet of water)	53	90

Well 105, Center NW¼ sec. 36, T. 3 N., R. 45 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Soil	1	1
Sand	20	21
Sandy silt and clay:		
Clay	16	37
Grand Island formation:		
Gravel	10	47
Ogallala formation:		
Sand	12	59
Clay	10	69
Gravel (12 feet of water)	11	80

Well 106, SE¼ sec. 21, T. 1 N., R. 45 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sandy silt and clay:		
Soil	9	9
Ogallala formation:		
Rock	3	12
"Magnesia"	18	30
Gravel	2	32
Stone	88	120

Well 107, SW¼SE¼ sec. 22, T. 1 N., R. 45 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation and sandy silt and clay:		
Sand	90	90
Ogallala formation:		
Rock	1	91
Gravel	36	127

Well 108, Center sec. 27, T. 1 N., R. 45 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sandy silt and clay:		
Soil	7	7
Ogallala formation:		
"Magnesia"	20	27
Rock and gravel	73	100

Well 109, Center E½NW¼ sec. 15, T. 3 N., R. 44 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Sand	40	40
Grand Island formation:		
Gravel (20 feet of water)	20	60

Well 110, Center N½SW¼ sec. 31, T. 3 N., R. 44 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sandy silt and clay:		
Soil	2	2
Sand	15	17
Ogallala formation:		
"Magnesia"	10	27
Clay	20	47
Gravel	13	60
Clay	10	70
Gravel (16 feet of water)	20	90

Well 111, Center NW¼ sec. 7, T. 2 N., R. 44 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Sand	20	20
Ogallala formation:		
"Magnesia" and clay	15	35
Gravel	35	70
Rock	2	72

Well 112, Middle W line SW¼ sec. 27, T. 2 N., R. 44 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Soil	4	4
Sandy silt and clay:		
"Magnesia"	15	19
Ogallala formation:		
"Magnesia" and rock	19	38
Rock	15	53
Clay	18	71
Rock	5	76
Brown porous rock (8 feet of good water)	14	90

Well 113, Center W½ sec. 33, T. 2 N., R. 44 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Soil	4	4
Sand	40	44
Ogallala formation:		
Clay (12 feet of water)	1	45

Well 114, N½NE¼ sec. 4, T. 1 N., R. 44 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Valley fill:		
Soil	2	2
Clay	45	47
Ogallala formation:		
Gravel	18	65
Sand	10	75

Well 115, SW corner of NE¼ sec. 6, T. 1 N., R. 44 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Soil:		
Soil	2	2
Ogallala formation:		
Rock	107	109
Gravel	6	115

Well 116, on sec. line between secs. 11 and 14, T. 1 N., R. 44 W.

[Authority, Barb, C. F., (1946, p. 430)]

	Thickness (feet)	Depth (feet)
Formations unknown (well was taken over by Yuma Valley Land Co. from the Hessig Drilling Co., at 2,410 feet):		
Lime, white	125	2,535
Brown shale	40	2,575
Brown shale and soapstone	125	2,700
Sand, gray, dark	8	2,708
Black shale	32	2,740
Brown shale, sandy	20	2,760
Black shale; soapstone	135	2,895
Water sand, gray	10	2,905
Black shale	25	2,930
Sandy, gray shale, dry	12	2,942
Black shale	8	2,950
Sandy, gray	10	2,960
Shale, gray	10	2,970
Sandy, white	10	2,980
Shale, gray	15	2,995
Shale, black	20	3,015
Sandy shell	5	3,020
Sandy, gray	10	3,030
Black shale	10	3,040
Sandy, gray	15	3,055
Gray shale	15	3,070
Sandy shale	25	3,095
Gray shale	35	3,130
Black shale, sandy; showing oil and gas	5	3,135
Brown shale	5	3,140
Blue shale, dark	10	3,150
Blue shale, light	15	3,165
Light-blue shale, hard crystals	90	3,255
Blue shale, dark; pyrites	5	3,260
Sandy lime; lime chalky, gray-white shells	3	3,263
Gray slate	12	3,275
Total depth		3,305

Well 117, SE corner of SW¼ sec. 24, T. 2 N., R. 44 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sandy silt and clay:		
Soil	3	3
"Magnesia"	8	11
Clay	20	31
Ogallala formation:		
Gravel	20	51
Rock	23	74
Gravel	18	92
Rock	12	104
Gravel (10 feet of good water)	26	130

Well 118, Center N½NE¼ sec. 12, T. 1 N., R. 44 W.

[Authority, Ernest Price, local driller]

	Thickness (feet)	Depth (feet)
Valley fill:		
Topsoil	4	4
Clay	3	7
Gravel	18	25
Clay	4	29
Water-bearing gravel	21	50

Well 119, NW corner NE½ sec. 25, T. 1 N., R. 44 W.

[Authority, Ernest Price, local driller]

	Thickness (feet)	Depth (feet)
Peorian loess:		
Brown clay	45	45
Ogallala formation:		
Gravel and sand	94	139
Water gravel	12	151

Well 120, SW¼NW¼ sec. 33, T. 3 N., R. 43 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sandy silt and clay:		
Sand	6	6
Ogallala formation:		
"Magnesia"	15	21
Quicksand	5	26
Clay	34	60
Gravel (25 feet of water, hard)	5	65

Well 121, NW corner sec. 9, T. 2 N., R. 43 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Sand	45	45
Ogallala formation:		
Quicksand	5	50
"Magnesia"	10	60
Rock	3	63
Gravel	9	72

Well 122, SW¼ sec. 9, T. 2 N., R. 43 W.

[Authority, Ernest Price, local driller]

	Thickness (feet)	Depth (feet)
Sand Hills formation and sandy silt and clay:		
Top soil	3	3
Brown clay	4	7
Ogallala formation:		
"Magnesia"	120	127
Gravel	5	132
Clay	3	135
Water-bearing gravel	8	143

Well 123, Middle S. line NW¼ sec. 17, T. 2 N., R. 43 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Sand	10	10
Ogallala formation:		
"Magnesia"	25	35
Sand rock	30	65
Gravel	5	70

Well 124, NW¼ sec. 17, T. 2 N., R. 43 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sand Hills formation:		
Sand	10	10
Ogallala formation:		
"Magnesia" and sand rock	25	35
Sand rock	29	64
Rock	1	65
Gravel	2	67

Well 125, NW corner SE¼ sec. 24, T. 2 N., R. 43 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Sandy silt and clay and Grand Island formation:		
Sand	22	22
Ogallala formation:		
Rock	2	24
Gravel	1	25

Well 126, NW¼SW¼ sec. 31, T. 2 N., R. 43 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Dune sand and sandy silt and clay:		
Sand	101	101

Well 127, N½ sec. 2, T. 1 N., R. 43 W.

[Authority, Colorado State Highway Department, 3 holes at bridge site]

	Thickness (feet)	Depth (feet)
H-1		
Valley fill:		
No core taken (water at 10.6 feet)	21.5	21.5
Fine sand	.7	22.2
Coarse gravel	1.3	23.5
Fine compacted sand	1.0	24.5
Pierre shale:		
Black shale	.5	25.0
H-2		
Valley fill:		
Sandy clay	14.7	14.7
Pierre shale:		
Black clay shale	.6	15.3
H-3		
Valley fill:		
Fine sand (water at 0.2 foot)	11.3	11.3
Clay	.4	11.7
Pierre shale:		
Black clay shale	.3	12.0

Well 128, Center W½NW¼ sec. 31, T. 1 N., R. 43 W.

[Authority, Ernest Price, local driller]

	Thickness (feet)	Depth (feet)
Peorian loess:		
Topsoil	8.0	8.0
Clay loam	120.0	128.0
Ogallala formation:		
Sand	10.0	138.0
Gravel and clay	2.5	140.5
Sand	7.5	148.0
Sand	8.0	156.0
Brown clay		

Well 129, SE corner NW¼ sec. 6, T. 1 N., R. 43 W.

[Authority, Ernest Price, local driller]

	Thickness (feet)	Depth (feet)
Valley fill:		
Topsoil	4.0	4.0
Sand (white)	75.0	79.0
Gravel	.3	79.3
Sand		
Pierre shale:		
Sand		

Well 130, Middle S. line SW¼ sec. 6, T. 1 N., R. 43 W.

[Authority, Ernest Price, local driller]

	Thickness (feet)	Depth (feet)
Valley fill:		
Black soil	10	10
Clay	5	15
Sand (water)	4	19
Clay		
Gravel		63
Mud clay		
Pierre shale:		
Shale		

Well 131, Middle W. line NE¼ sec. 7, T. 1 N., R. 43 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Soil	1	1
Rock	9	10
Sand	10	20
Clay	11	31
Gravel	27	58
Clay and gravel	15	73
Clay	10	83
Rock	10	93
Clay	4	97
Gravel	23	120

Well 132, NW¼SE¼ sec. 7, T. 1 N., R. 43 W.

[Authority, Ernest Price, local driller]

	Thickness (feet)	Depth (feet)
Ogallala formation:		
Rock ("magnesia" and lime)	125	125
Gravel	10	135
Pierre shale:		
Shale	----------	----------

Well 134, Middle S. line SE¼ sec. 28, T. 1 N., R. 43 W.

[Authority, Ground Water Branch, Geological Survey]

	Thickness (feet)	Depth (feet)
Peorian loess:		
Soil	3	3
"Magnesia"	20	23
Clay	20	43
Ogallala formation:		
Gravel	25	68
Clay	18	86
Rock	15	101
Gravel	26	127

Well 135, SE¼SE¼ sec. 5, T. 1 N., R. 42 W.

[Authority, Colorado State Highway Department, 3 holes at bridge site]

	Thickness (feet)	Depth (feet)
H-4		
Valley fill:		
Sand (water at 1 foot)	27.9	27.9
Pierre shale:		
Black clay shale	.3	28.2
H-5		
Valley fill:		
Fine sand	35.2	35.2
Sandy clay	1.7	36.9
Pierre shale:		
Black sandy shale	.6	37.5
H-6		
Valley fill:		
Sand and sandy clay (water at 8.5 feet)	36.0	36.0
Pierre shale:		
Black sandy shale	1.4	37.4

Well 136, Middle S. line NE¼ sec. 9, T. 1 N., R. 42 W.

[Authority, Colorado State Highway Department, 3 holes at bridge site]

	Thickness (feet)	Depth (feet)
H-7		
Valley fill:		
Sand, streaks of sandy clay (closed at 38.3)	38.3	38.3
H-8		
Valley fill:		
Sand, sand and clay, fine sand	40.0	40.0
H-9		
Valley fill:		
Sand and sandy clay (water at 9.5 feet)	36.2	36.2